The Essence of Astronomy

Things Everyone Should Know About the Sun Moon and Stars


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THE PLEIADES

A long exposure photograph showing the wonderful nebulosity enveloping this whole group Viewed with the eye these stars here shown drowned in foggy light shine clear and brilliant From a photograph taken at the Yerkes Observatory

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By

Edward W. Price

Illustrated

G. P. Putnam's Sons
New York and London
The Knickerbocker Press
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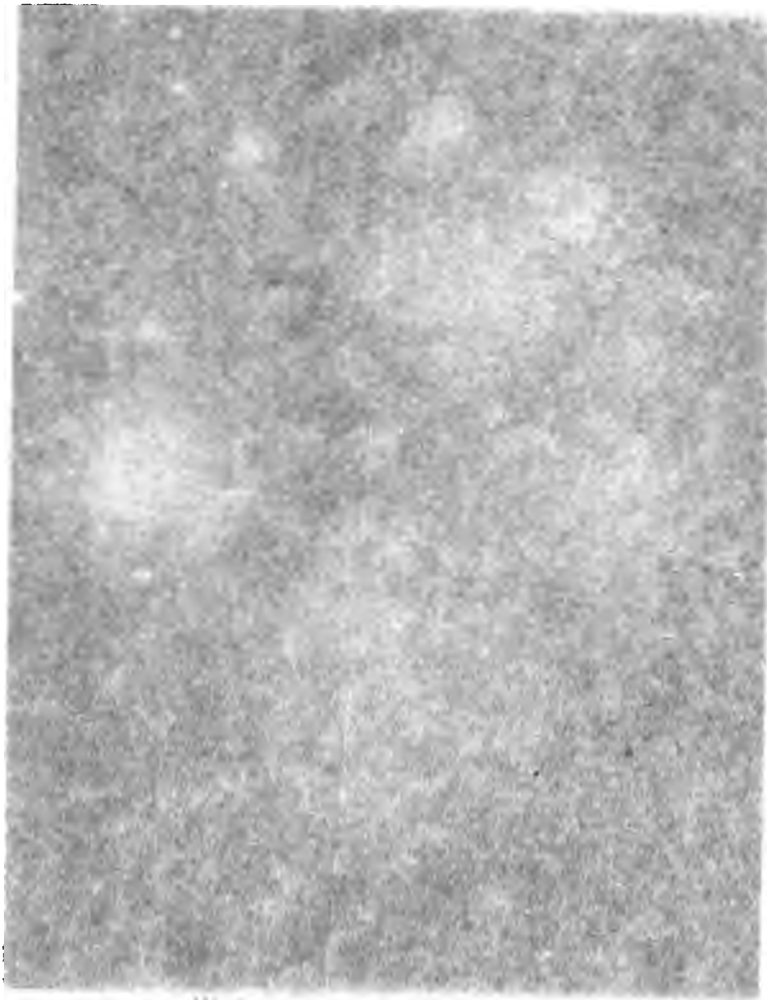

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To

MY "ASTRONOMICAL WIDOW"

PREFACE

This small volume is not offered to the public as an original treatise upon its subject. It is merely a *brief* compilation of the facts of Astronomy, as presented by the acknowledged authorities, together with some slight reference to various theories not yet substantiated.

All technical terms, and all mathematics, except certain simple figures necessary for description and comparison, have been omitted, and no signs or symbols have been used except those to be found in the ordinary almanacs. These last do not appear in the text, but are given on a separate page in the back part of the volume. In spite of these omissions, it is hoped that this compilation may have some value as a *concise* reference book for the general reader or for schools. With a view toward simplicity, the writer has given no *exact* figures such as would be necessary in an advanced textbook, but has stated all numerical values in the closest *approximate* terms.

There has been added—what the compiler has never happened to see before—a tabulated chronology of the main events in the history of Astronomy, and also a chapter very briefly describing the various instruments now used in the great observatories.

In the bibliography at the end of the volume, are listed the titles of all the books used for reference in checking the descriptions, figures, and statements given. To the authors of all of these books, the writer is much indebted. Following each title is a short note, endeavoring to present an idea of the scope of that volume. If, upon reaching this bibliography, the reader is enough interested in the greatest and most ancient of sciences to turn to some of these real books upon the subject, the main purpose of these pages will have been accomplished.

It will be noticed that the greater part of the volume is devoted to the Solar System, and that to the Universe as a whole is given but scant space. It is about the Solar System that the astronomical *facts* swarm thickest, while, though a marvelous amount is really known about the vast stellar hordes, it is often difficult to separate fact from logical surmise. The more essential of the stellar facts, and many of the generally accepted and most logical of those theories which should interest the general reader, are, however, given.

The grouping, or apparent grouping, of the stars into constellations has not been touched upon. It is not possible to give in short space enough description of them to make their positions clear. The bibliography refers to several works admirably written for just that purpose.

Nor has it been possible to find room for any of the great discussions concerning the beginnings of the Solar System. In passing, however, it may be said here that several theories, and attractively logical ones, have been advanced in the past few years since the rejection by most astronomers of the Nebular Hypothesis as conceived by Laplace.

E. W. P.

New York
February, 1914.

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It is a pleasure to acknowledge the permission to reproduce the above photographs so kindly extended by the Directors of the Yerkes Observatory, the Lick Observatory, the Harvard College Observatory, and the Lowell Observatory.

To them, and to Professor Lowell in particular, for his interest, trouble, and great courtesy, the author wishes to express his gratitude.

The Essence of Astronomy

The Essence of Astronomy

CHAPTER I

THE SOLAR SYSTEM

RUSHING through space, bound whither we know not, save for the mere direction, speeds the vast globe called the Sun, at a rate of nearly 12 miles per second. Around this falling body—and a true and stupendous fall it is—an almost infinite number of smaller bodies, ranging from tiny particles to great masses thousands of miles in diameter, revolve with a marvelous regularity and order. This is the Solar System. Although almost inconceivable in size, its huge dimensions shrink to microscopic estimates when we measure on its every side the unbelievable depths of space which bound its isolation. For countless centuries, the Sun and its family have been approaching, at a speed of over a million miles a day, a definite section of the Universe, and yet it seems no closer than thousands of years ago. In truth the Solar System is but a cluster of tiny motes dancing in the infinite.

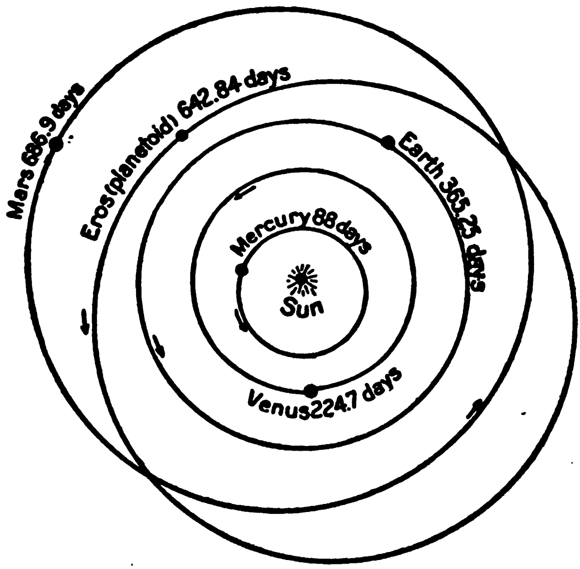
According to our present knowledge, the Solar System, measures over 5,000,000,000 of miles across, and these boundaries are decided only by the "stay-at-home" members of the family, the planets. How far those eccentric wanderers, the comets, may extend these limits, we cannot tell.

In the center of this great system, spins the Sun, a huge globular mass of flaming gases, inconceivably hot, giving forth practically all the light and heat for its whole family. This Sun is a *star*, as much so as any of the thousands we see at night twinkling in the skies, showing from their incalculable distances only as tiny points of light; the humiliating truth being that our Sun is, indeed, but one of the smaller stars, and it is only its nearness which blinds us to its true proportions.

Around itself, the Sun, by the mighty power of gravitation, swings, in the order named, the following eight bodies called planets: Mercury, Venus, the Earth, Mars, Jupiter, Saturn, Uranus, and Neptune, which all revolve in slightly elliptical orbits. The orbits of the planets lie approximately in the same plane (the plane of the ecliptic, as it is named), so that the shape of the Solar System as a whole is that of a great flat disk. These planets all shine only by *reflecting* a portion of the Sun's light. They have no light of their own. Their brilliancy is of wide range. This is mainly because of the difference in their distances from us, but is also due, in part, to the difference in their sizes and reflective power (*albedo*), as well as to their position in relation to the Sun and the Earth. Because of distance, Uranus is but barely visible to the naked eye, and Neptune is never seen without a telescope; while Mercury is so close to the Sun that it appears but at certain intervals, and then under perfect conditions only is visible without a glass. Four of the planets, however, Venus, Mars, Jupiter, and Saturn, are those "stars" which shine to the naked eye clear and bright, without the "twinkle" of the real stars, and two of them, Venus and Jupiter, are those which so often sparkle in our early evening and morning skies with such luster and brilliancy.

The inner four of the eight planets are comparatively small and dense, or heavy, and the outer four are large and light.

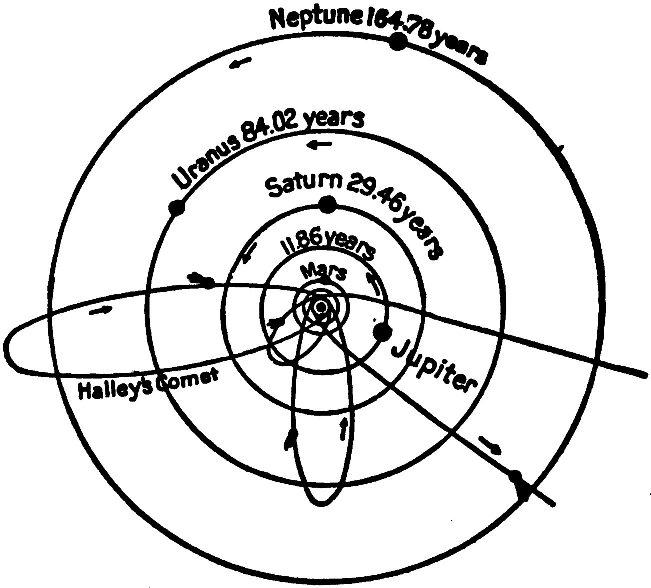
The periods of their revolutions about the



THE ORBITS OF THE TERRESTRIAL PLANETS
AND ONE OF THE PLANETOIDS
(*Drawn approximately to scale*)

Sun—their "years,"—vary with their distances from it, between 88 days and 164 years. This is in obedience to a definite law of motion which insists upon an exact relation between such times and distances.

The orbits of the planets in regard to the Sun



THE ORBITS OF THE MAJOR PLANETS
(*Drawn approximately to scale*)

are ellipses, it is true, but in relation to space they are, because of the motion of the Sun along its celestial path, vast *spirals;* so that, far from returning to the same spot in the Universe at the completion of one revolution about the Sun, a planet never passes over the same place twice.

Around most of these planets, revolve from one to ten smaller bodies, called moons or satellites. These satellites, of which our own Moon is one, shine also only by reflected light.

The Sun, planets, and satellites all rotate upon their axes, in periods ranging from a few hours to several months.

Between the orbits of Mars and Jupiter is a large number of still smaller bodies, called *asteroids* or *planetoids*. Of these, about 800 have been discovered, sweeping, each in its own orbit, as part of a great ring around the Sun.

Most unique of the solar family are the "fiery-haired" comets, those ancient portents of evil, which swing in narrow ellipses of great variety, some contentedly remaining within the planetary boundaries, and others rushing far into the emptiness beyond to return again to view only after hundreds and even thousands of years. Indeed, some astronomers believe that a large percentage of the comets are truly wanderers in space, which bow to the Sun but once, and pass on never to return.

Least in size, but by far the most numerous, are the meteors, chips, so-to-speak, from worlds in the making, some of which are herded together in vast swarms, while others pursue more lonely paths. But all, alike, obey the great law, and revolve in stated orbits around the Sun, until they collide with one of the planets, or, disturbed by a too close approach to such a large body, are swung into a new path that ends in the Sun itself. It is the fiery dissipation of a meteor, heated to a great temperature by the friction of our atmosphere, which causes the phenomenon of a "shooting-star."

It is probable, also, that a "cloud" of almost dust-like particles of matter extends through much of the Solar System, particles too small to be of appreciable size or weight. The existence of these is strongly suspected by reason, and is believed to be demonstrated by two phenomena, later described in Chapter XVII., the Zodiacal Light, and the Gegenschein.

There was for some time believed to be a planet body revolving about the Sun within the orbit of Mercury. This hypothetical planet was even given a name—Vulcan. Its existence has now, however, been absolutely disproved.

Also, far beyond Neptune, another planet is supposed to creep in its slow path. A systematic search for this has extended over many years, but has as yet been unsuccessful. If such a planet does exist, as seems likely, it must be at a vast distance, over four billions of miles, and probably is invisible even with the aid of our greatest telescopes. If it is found, it will be the photographic plate which "sees" it, and which will record its lazy motion across the skies.

A scale which helps one to remember the proportions of the Solar System is the following:

The Sun—a globe 2 feet in diameter		
Mercury—a mustard-seed	55	yards away from the globe
Venus—a small pea	95	" " " " "
The Earth—a large pea	143	" " " " "
Mars—the head of a rather large pin	215	" " " " "
The Asteroids—grains of sand	220–270	" " " " "
Jupiter—a large orange	740	" " " " "
Saturn—a small orange		nearly a mile away
Uranus—a marble		over a mile and a half away
Neptune—a larger marble		over two and a half miles away

All the members of the solar family will be taken up chapter by chapter, and it seems fitting to begin with the Sun itself.

CHAPTER II

THE SUN

THE Sun is the central body of the Solar System, and is far larger than all the other members of the system put together.

Its diameter is about 866,400 miles. Its surface is nearly 12,000 times that of the Earth, and its volume, or bulk, nearly 1,300,000 times as much as that of our planet.

Its mean, or average, distance from the Earth is not quite 93,000,000 miles.

The Sun rotates upon its axis in a *mean* time of 25 days, 7 hours, 48 minutes. The equatorial regions, or middle part, of the Sun turn considerably faster than the poles. That is, a point on the Sun's equator actually completes a full rotation sooner than a point in a higher latitude, each particle nearer the equator *slipping by* its neighbor nearer the pole. This, which cannot happen in the rotation of a rigid body like the Earth, is possible because of the Sun's lack of solidity.

Its axis is inclined to the ecliptic, as the plane of the Earth's revolution about the Sun is called, about seven degrees.

The Sun is moving through space in the direction of the bright star Vega at a rate of between 11 and 12 miles a second.

The mass, or the *amount of matter*, of the Sun is about 330,000 times that of the Earth; its density, or the *compactness of the matter*, is, however, only about one quarter. Its attraction for bodies at its surface is nearly 28 times that of the Earth. A body weighing here 200 pounds would on the Sun weigh nearly three *tons*.

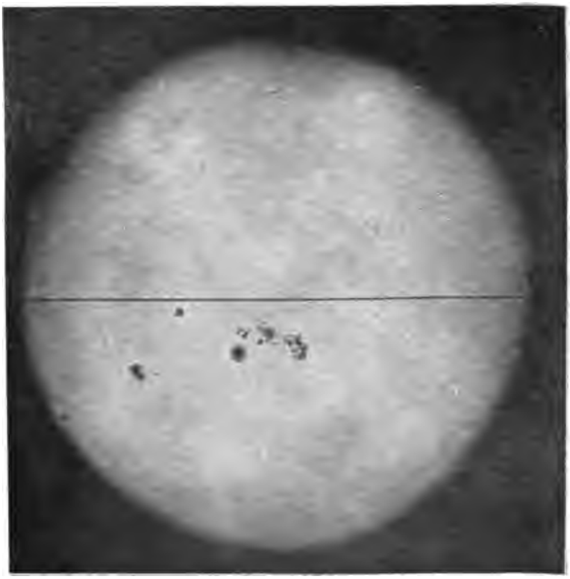
The Sun has a dense atmosphere, quite different, however, from our own.

The temperature of the Sun is very difficult to measure. It is, according to the best authorities, about 12,000 degrees Fahrenheit.

The brilliance of its light is also very difficult to estimate. This, at its surface, must be at least 150 times that of a calcium light, one of the brightest lights that we can produce artificially.

Of the light and heat of the Sun, the Earth intercepts but $\frac{1}{2,200,000,000}$ part.

Through a telescope, the surface of the Sun shows a strangely mottled effect, with here and there a dash of more brilliant light. From time to time, there appear, also, great black-looking spots, these seeming black *only by contrast* to the rest of the surface. These are the so-called Sun-spots, and seem to be vast cyclonic holes in the superficial gaseous layer, or atmosphere, surrounding the main body of the Sun. The frequency of these spots varies in a cycle of about eleven years, the reason for which is not known. These spots also never appear near the poles of the Sun, but at the beginning of a cycle show in the middle latitudes, and subsequently break out nearer and nearer the equator, close to which they are present during the period of greatest frequency. The size of the spots is of great range. Some are comparatively small, and are visible only through the great telescopes, while others have been measured well over 100,000 miles in diameter, and have been easily seen with the naked eye. The duration of the spots also differs much. Some last for a few hours only while others appear, with but slight changes, for two or three months. It was by observation of the spots that the time of the Sun's rotation was found. Incidentally, it is interesting to know that when Galileo first announced his



THE SUN

Showing a group of sun-spots. Note in the spots the dark center (the umbra) and the lighter border (the penumbra)
From a photograph taken at the Yerkes Observatory

discovery of the spots, his statement was met with scornful derision. As if there could be *blemishes* upon the face of our great luminary!

During a total eclipse of the Sun, when the blinding light of the globe itself is cut off, there are seen to shoot forth great sprays and tongues of flame, to the height of sometimes over 300,000 miles. For many years these were supposed to be appendages of the Moon, and in consequence to be comparatively small, but they have long since been proven to belong to the Sun. These appalling flames lash out with a speed of often several hundred miles a *second*, and bespeak an explosive force behind them almost inconceivable. These eruptions, or prominences as they are called, undoubtedly occur at all times over most of the Sun's surface. We can see, however, only those which extend beyond the edge of the apparent disk. These prominences can now be studied without waiting for an eclipse by means of the instrument known as the spectroscope. There are also to be seen great cloud-like masses floating high above the surface of the Sun as do clouds in our atmosphere. These are literally clouds of vapors, for the most part hydrogen, helium, and calcium. They are sometimes called "floating prominences." They last much longer than the eruptive prominences.

Another prominent feature of the Sun, seen *only* at a total eclipse, however, is the corona. This is a wonderfully soft radiance which extends often for millions of miles, in great curving wings and streamers, and always shows as a glorious halo around the black center of the eclipse. Those who have been so fortunate as to have seen a total eclipse speak of the corona as a most marvelously beautiful sight. The nature of the corona is not known. Under the analysis of the spectroscope, it shows a substance which, as yet, has not been found on the Earth. This has been called coronium.

There has been much speculation as to the means by which the Sun maintains its great temperature when it continues radiating such enormous quantities of heat. It is easily demonstrated that no combustion, or burning, as we know such, can account for this. The geologists demand millions of years as necessary to account for the condition of the Earth; and the Sun must be older than the Earth. Grant any such age, and, under the combustion theory, the Sun would have been a dead cinder long ago.

While still believing in the contraction theory, astronomers are now inclined to admit the possibility of a radio-active condition which may have a much greater effect than is supposed.

The contraction theory is based upon the fact that, given a gaseous mass of matter the size of the Sun at present, heated to a high temperature, this mass, by contracting in volume, that is by falling together in consequence of gravitational pull, less than *a mile in diameter per year*, or $\frac{1}{866,000}$ of its diameter, could radiate the amount of heat which the Sun does now, and still have enough left to keep the remaining *smaller* bulk of itself at the original temperature, or *even to raise the temperature* slightly higher. In other words, the Sun, although losing a great *amount* of heat, may nevertheless be growing hotter day by day. This sounds paradoxical for the moment, but a consideration of the difference between *amount of heat* and *temperature* will make it clear.

Because of a curious optical illusion, it is not possible to measure with great accuracy any very brilliant object. For this reason, we cannot tell yet whether the Sun is really decreasing in size. A decrease of fifty miles in its diameter would not be noticeable.

The Sun also acquires a certain amount of heat by the impact of meteors, which doubtless fall in great numbers to its surface. As, however, the fall into the Sun of a body as large as the Earth would produce heat enough to last only for a comparatively short time, it seems hardly possible that the fall of meteors can be considered as a real factor in the continuation of the Sun's store.

Although the Sun is but a small star, it is, nevertheless, to us the most important of all stars. We might dispense with a great proportion of the light received from this enormous body, but without its *heat* we should have no existence. It is the heat of the Sun which stimulates our vegetation, and vegetation supports directly or indirectly all animal life. It is the heat of the Sun which causes all atmospheric disturbances, and in consequence keeps our air constantly freshened. It is the heat of the Sun which causes water evaporation and the resultant rains, maintaining the purity of our water supplies. In fact, it is the heat of the Sun which is primarily responsible for all the changes necessary to make the Earth habitable. From it we derive all our sustenance as well as all forms of mechanical power.

SOLAR PROMINENCES

These are about 60,000 miles in height. The two photographs show the vast changes occurring in ten minutes.
October 10, 1910
From photographs taken at the Yerkes Observatory

The proportions and properties of the Sun are so vast that it is practically impossible to grasp them without some comparison with familiar standards. A few of these are given below.

If the Earth were placed at the center of the Sun, the Moon revolving round the Earth at its present distance would reach only a little more than half way to the surface of the Sun. There would still be over 190,000 miles between the Moon and the surface. And yet, a train running a mile a minute would take three and one half months to cover a distance corresponding to that which separates the Moon from the Earth.

This same train, which would go round the Earth in seventeen days, would require five *years* to make the circuit of the Sun.

If the Sun were a flat disk, as it appears, 109 globes as large as the Earth, touching edge to edge, would be necessary to reach across it.

We receive from the Sun about 600,000 times as much light as we get from the Moon. Were the sky covered with full moons it would not approach the radiancy of daylight.

The heat of the Sun, to quote the late Prof. Young, whose estimate of the temperature was given above, may be illustrated by the fact that "if a bridge of ice could be formed from the Earth to the Sun by a column of ice, 2.1 miles square and 93,000,000 miles long, and if in some way the entire solar radiation could be concentrated upon it, it would be melted in *one second*, and in *seven more* would be dissipated in vapor."

CHAPTER III

MERCURY

MERCURY is the smallest of the bodies called planets, and revolves nearer to the Sun than any of the others.

Its diameter is about 3030 miles, nearly half as much again as that of our Moon. Its surface is about one seventh that of the Earth, and its volume about one eighteenth.

Its mean, or average, distance from the Sun is 36,000,000 miles. Its elliptical orbit is more eccentric, or elongated, than those of the other planets, and its distance from the Sun varies between 43,500,000 miles and 28,500,000 miles.

Its distance from the Earth at its closest approach is about 50,000,000 miles, and when farthest from it, about 136,000,000 miles.

Mercury revolves around the Sun in very nearly 88 days. This is the "year" of Mercury.

It rotates upon its axis in the same time, 88 days, and in consequence always turns the same side toward the Sun, this side being in perpetual daylight, the other in perpetual night.

Its axis is perpendicular to the plane of its orbit about the Sun. There are upon Mercury, therefore, no *seasons* such as we experience on the Earth.

It moves in its path of revolution at a mean speed of about 29 miles per second. This speed varies, however, between about 36 miles per second, when nearest the Sun, and about 23 miles per second, when farthest away.

The mass of Mercury is not definitely known. According to the latest measurements, the density of the planet is somewhat less than that of the Earth. The weight of Mercury is, therefore, slightly less than five and one half times that of a globe of water the same size. If these estimates are correct, as seems probable, its attraction for bodies at its surface is about one half that of the Earth's. That is, a body weighing 200 pounds here would weigh less than 100 pounds there.

Mercury has practically no atmosphere.

It receives from the Sun on an average nearly seven times as much light and heat as does the Earth; when nearest the Sun (or at perihelion, as this point of a planet's orbit is called) over nine times as much, and when farthest from the Sun (aphelion) over four times as much. This variation in the heat received does, therefore, produce a sort of change of seasons, and a very severe one.

Mercury reflects back from its surface about 14 per cent. of the light received.

Viewed with a telescope, Mercury shows "phases," as does our Moon (see Chapter VI.). In passing from "new" to "full" and back again about 115 days are consumed. If the Earth were stationary, the phases would occupy but 88 days, the time of Mercury's revolution, but as the Earth also moves in its orbit about the Sun in the same direction as does Mercury, it takes more than one complete revolution of the latter to bring it again between the Sun and the Earth. The phases, of course, result from the relative positions of the three bodies, the Sun, Mercury, and the Earth, as the phases of the Moon result from the position of the Moon in relation to the Earth and the Sun.

The plane of Mercury's orbit is inclined, or tilted, to the ecliptic (the plane of the Earth's orbit) at an angle of about seven degrees. It is for this reason that the planet does not pass *directly* between us and the Sun every revolution. About twelve times a century it *does* pass directly between us and the Sun, and is then visible, with a telescope, as a small black dot upon the Sun's disk. Such an occurrence is called a transit.

Mercury has no moon of visible size.

As the orbit of Mercury is inside that of the Earth, the planet is never seen *at night*, but is visible at certain times close to the horizon, only just after sunset in the west, or just before sunrise in the east. Because of this, and because of the haze which is usually prevalent in the Earth's atmosphere, it is viewed probably less than any other celestial body visible to the naked eye. It is so necessary to have good seeing conditions, that it is said the celebrated astronomer Copernicus died without observing Mercury. This sounds extreme, for the writer has picked it up several times with an opera-glass and naked eye from a city window. When seen with the naked eye, it shines as a bright star, showing a reddish tint because of the atmospheric disturbances and the horizon haze through which its light must penetrate. It usually seems to "twinkle" somewhat for the same reason, and, indeed, is sometimes spoken of as "The Twinkler."

To avoid these bad "seeing" conditions, the astronomers study Mercury in daylight. This is possible with large telescopes, though, of course, the planet is then quite invisible to the naked eye, being lost in the glare of the sunlight.

There seems no possibility of life as we know it upon Mercury. The atmosphere is of such rarity as to be insufficient to support such life; and the terrific heat to which the faithful sunward side of the planet is constantly subjected adds greatly to the improbability. The lowest temperature there is *above* that of the boiling point of water here, and the greatest is more than twice as hot. The dark side is, of course, constantly exposed to the awful cold of space, suffering also from the lack of an atmospheric blanket. The planet, therefore, revolves almost certainly as a dead world, scorched on one side, and frozen on the other.

One curious effect of the great variation in the distance of Mercury from the Sun is that in about six weeks (44 days) the latter, viewed from the planet, apparently grows to more than double its size and brilliancy, and in the next six weeks shrinks again. The average size of the Sun, seen from Mercury, is somewhat more than twice its size as viewed from the Earth.

In spite of the difficulty experienced in viewing the planet with the unaided eye, we have records of observations of Mercury made at Nineveh 2500 years ago.

CHAPTER IV

VENUS

VENUS, reckoning on an ascending scale, is the third in size of the Sun's family of planets. It is larger than Mercury and Mars, and just smaller than the Earth. It revolves in an orbit which lies between that of Mercury and that of the Earth.

The diameter is nearly 7700 miles, the Earth's being 7918. Its surface is about nine tenths that of the Earth and its volume about nine tenths also. Venus may be slightly flattened at its poles; no accurate measure has been obtained however.

Its mean distance from the Sun is almost exactly 67,200,000 miles. Its orbit is the least elliptical of all the planets; so approaching a true circle that the variation of its distance from the Sun need not be considered.

Its distance from the Earth varies between 25,000,000 miles when nearest to it, to about

160,000,000 miles when farthest from it and on the other side of the Sun.

It revolves about the Sun in 224.7 days, this being the year of Venus.

The rotation upon its axis is not *definitely* known. It seems almost certain, however, that, like Mercury, the time of rotation equals the time of revolution, and that the planet therefore turns always the same side to the Sun. If this rotation is correct, as now believed, the axis of the planet is perpendicular to the orbit. Recent observations seem to substantiate this supposition. Venus therefore lacks seasons, as does Mercury.

It moves in its orbit around the Sun at an almost unvarying speed of 22 miles per second.

Its mass is somewhat less than eight tenths that of the Earth; and its density somewhat more than eight tenths. Venus weighs, therefore, nearly five times as much as a globe of water the same size.

Its attraction for bodies on its surface is also somewhat more than eight tenths that of the Earth. A body weighing 200 pounds here would weigh on Venus about 165 pounds. Venus has apparently a rather dense atmosphere. The spectroscope shows the presence of water; and one of the reasons that definite observations of the planet are so difficult to obtain is because of the perpetual veil of cloud between us and its surface.

It receives from the Sun about twice as much light and heat as does the Earth. The cloud-veil, however, probably tempers this to a climate not much more severe than our tropics at times.

Also, because of the cloud-veil the reflective power of the planet is very high. It throws back over 75 per cent. of the light it receives from the Sun. This dazzling brilliancy adds to the difficulty of observing.

Viewed with a telescope Venus, too, shows "phases" as does our Moon (Chapter VI.). This fact was first observed by Galileo in 1610. The period between "new" to "new" occupies about 580 days.

The plane of its orbit is inclined to that of the Earth at an angle of about 3.5 degrees. This would seem to indicate that it should pass directly between us and the Sun (transit) more often than Mercury. However, because of the relation between the times of revolution of Venus and the Earth these transits are comparatively rare, occurring about at the rate of two to the century. The last was in 1882. The next will be 2004.

Venus, like Mercury, has no moon of sufficient size to see.

The orbit of Venus being, also, within that of the Earth the planet is never seen *late* at night. Its orbit, however, is so much greater in diameter than Mercury's that it recedes much farther from the Sun, and when at the best distance for observation does not "set" until some hours after the "day-star." It is seen, nevertheless, only in the western sky after sunset or in the eastern sky before sunrise.

To the naked eye the planet is, with the exception of the Sun, the Moon, and an occasional comet, the most brilliant of all celestial bodies. It has twelve times the brightness of the most brilliant star, and shines with a silvery light. When at its best it can be seen as a tiny point of light in *full daylight.* As has been said, this very brilliancy makes it most difficult to observe, and it is, on the whole, a disappointing telescopic object. Like Mercury, it is best observed in the daytime, when some of its glare is overcome by the daylight.

That there *may* be on the Sunward side of Venus a life approaching that of our tropics seems possible. There are no known conditions that would appear to prevent the existence of such. It seems hardly probable, however, that the atmosphere of the planet can carry enough warmth to its *dark* side to make this habitable.

Venus has been known and recognized since the earliest days of astronomy.

CHAPTER V

THE EARTH

The Earth is the third of the planets in order of distance from the Sun, and is the fourth in size reckoning on an ascending scale. It is the largest of the four minor or terrestrial planets.

Its mean diameter is 7918 miles. It shows what on Venus or Mercury cannot be measured —a flattening at the poles, so that the diameter from pole to pole is 27 miles shorter than the diameter measured through the equator. This bulge at the equator was formed, while the Earth was in a molten or plastic condition, by the centrifugal force developed by its rotation about its axis.

Its surface comprises about 187,000,000 square miles, of which nearly three quarters are covered by water. Its volume is about 260,000,000,000 cubic miles.

Its mean distance from the Sun is very nearly 93,000,000 miles. Its orbit is slightly elliptical so that this distance varies about 3,000,000 miles. The Earth is *nearest* the Sun early in January, and farthest from it in early July. The mean distance 93,000,000 miles is one of the *astronomical units* of measurement.

The Earth revolves about the Sun in 365 days 6 hours 9 minutes 9 seconds. This is its true year. There are two other "years."

It rotates upon its axis in 23 hours 56 minutes and 4 seconds.

The difference between the various "years" spoken of, and the 3 minutes and 56 seconds difference between the time of rotation and the day, cannot be discussed in the space available here. Any of the larger general works listed in the bibliography gives a full explanation of the reasons, and the effect of these apparent discrepancies in time.

The axis of the Earth is inclined to the plane of its orbit about 23.5 degrees. This inclination, although actually varying somewhat, may be considered as fixed, and the *direction* of the inclination may also, for the moment, be considered fixed; that is, during a revolution, the Earth points its axis constantly at the same point in space. It is this inclination which is the cause of our seasons. When the north pole of the Earth's axis is leaning away from the Sun, it is winter, in the northern hemisphere, since the Sun is, in consequence, above the horizon for a shorter part of the day; and its rays strike the surface of the Earth there obliquely, and as a result with less power; these conditions more than compensating for the nearer approach of the Earth to the Sun during the winter months. Half a year, or half a revolution, later, the north pole of the Earth's axis is leaning toward the Sun, and we have summer, or the hot season, since conditions are just the reverse. Of course, the seasons in the southern hemisphere are exactly the opposite of those in the northern, but are somewhat more intense, since it is summer when the Earth is also nearest the Sun, and winter when it is farthest away. Between winter and summer are the seasons of autumn and spring, when the axis of the Earth points neither toward nor away from the Sun and we have more equitable conditions of temperature.

The Earth moves in its orbit with a mean speed of nearly 18.5 miles a second, covering in its revolution each day about 1,500,000 miles. It moves slightly faster in January when nearest the Sun, and slower in July when farthest away.

Its density is a little more than 5.5 times that of water. A ball the same size made entirely of granite would weigh only about one half as much as the Earth.

Its atmosphere is comparatively dense, having at sea level a pressure of about 15 pounds to the square inch. This atmosphere acts as does the glass of a hot-house, preventing the Earth on its night side from radiating all its day-acquired heat into space. The atmosphere also tempers the heat of the Sun's rays as they strike the Earth.

Were it not for the air and dust suspended in the air the diffusion of daylight would not occur. Where the Sun's rays fell direct there would be brilliant illumination, but elsewhere the shadows would be inky black. The light is now spread by the progressive reflection from the countless ever-present dust particles. It is only this refraction and diffusion of the Sun's light that prevents our seeing the stars in the daytime. Without it the sky would be a dead black, set with the brilliance of the stars as steady untwinkling points, and the Sun would appear as a glowing white disk. From an observational astronomer's point of view nothing could be better.

The atmosphere also protects us from the constant bombardment of meteors (see Chapter XV.), which are fused to dust before they reach the Earth itself. It is partly from watching and studying the flights of meteors through the air that the latter has been estimated to extend about 100 miles from the Earth's surface. It is too rare for us to breathe at a height of about seven miles.

Owing also to the rather dense atmosphere it is probable that the reflecting power (albedo) of the Earth is high.

It is the plane of the Earth's orbit (the ecliptic) which astronomers take as the standard plane of the planetary revolutions, comparing the inclinations of the other planetary orbits with it.

The Earth is still at a high temperature. Owing to the tremendous pressure it is impossible that it be now a molten ball with a crust surrounding it, as was believed for many years. The heat at a great depth, however, is probably quite hot enough to melt the most refractory substances, were they not compressed to such an extent. The study of earthquake shocks has demonstrated that, as a whole, the Earth is nearly as rigid as a steel ball.

The motions of the Earth in space are very complex. The more evident of these are the yearly revolution, and the daily rotation. Beside these, there are, the great motion together with the Sun and the rest of the planets in the general direction of the brilliant star Vega, at the rate of about 12 miles a second; and eight other motions, some of them "wobbles" on its axis like an unevenly spinning top, and others waverings in its orbit—because of the changing relative direction of the Moon and the other planets, and the consequent variation of gravitational pull. There are in all eleven motions.

One of the small "wobbles" of the Earth produces an actual wandering of the poles, and a consequent ceaseless change in the latitude of every place upon the globe. This wandering is a matter of but a few yards, yet it can be followed with great accuracy, since the change in latitude causes a measurable shift in the position of the stars.

It is interesting to know that, though the

Earth's orbit in relation to the Sun is a closed curve, this deviates from a straight line only about one ninth of an inch in 18.5 miles, the distance traversed by the Earth in one second.

The Earth possesses a magnetic force which directs the needle of the compass. This force is subject to periodic and sporadic changes which cannot be discussed here. In passing, however, it may be said that many of these changes, possibly all of them, are produced by disturbances *in the Sun;* the regular "variation of the magnetic needle" being synchronous with the Sun-spot cycle of about eleven years.

It is this magnetic force that is in some way responsible for the *Aurora*, that marvelous luminous display which is witnessed often in high latitudes both northern and southern, the exact explanation for which has not yet been found.

The magnetic poles of the Earth are not located at the poles of its axis of rotation, but at considerable distances from them. Neither are these magnetic poles constant in position, their periodic and regular change of location giving rise to the variation of the compass just spoken of.

One of the effects of the comparatively rapid rotation of the Earth is that, at the equator, everything weighs less (that is, is pulled toward the Earth's center with less force) than at any point farther north or south. At the equator the centrifugal force developed by the spin of the Earth is at its strongest, and lessens in power as the latitude increases until, at the poles, it ceases to exist. A spot at the equator travels at over a thousand miles an hour, while at the poles it is merely *turned around* once in twenty-four hours. Also, the fact that the polar diameter of the Earth is less than the equatorial diameter places a point at the pole somewhat nearer the center of the Earth than a point on the equator. This aids in lending an object weight.

This difference in weight is slight, but is readily measurable, of course only with a spring scale. In a weight balance the marked weights are affected in exactly the same proportion as the objects weighed, and, therefore, no difference would be shown.

CHAPTER VI

THE MOON

THE Moon is the only visible satellite of the Earth, and revolves about it. It is probable that all the planets, and their larger satellites, including the Earth and the Moon, swing in orbits about them stray bits of "world-dust" that their attraction has captured, but as regards the Moon and the near planets these must be very small not to have been discovered.

The diameter of the Moon is 2162 miles; like Venus and Mercury it shows no polar flattening.

Its surface contains about 15,000,000 square miles; about one thirteenth that of the Earth. Its volume is about one fiftieth that of the Earth. The dimensions of the Moon are much greater in proportion to the Earth than those of any other satellite to its primary.

Its mean distance from the Earth is nearly 239,000 miles. Its orbit, like all celestial orbits, is more or less elliptical and its distance may vary between slightly more than 221,000 miles and 253,000 miles. Its usual variation is such, however, that in one revolution it amounts to a difference in distance from us of about 25,000 miles.

It revolves around the Earth in 27 days 7 hours 43 minutes and 11.5 seconds.

It rotates upon its axis in the same time, and, in consequence, always keeps the same side turned to the Earth, as do Mercury and Venus to the Sun. It is probable that nearly all the satellites of the planets have this same relation between their revolution and their rotation. Because of certain variations in the Moon's motion, both a "nodding" and a "shaking" of its head, so to speak, we see first somewhat around one side and then somewhat around the other; in all about four sevenths of the entire surface can be seen. Its axis is about perpendicular to the plane of its orbit.

The Moon moves in its revolution around the Earth at a mean speed of about 37 miles per minute.

Its mass is about $\frac{1}{81}$ that of the Earth; its density about three fifths, or nearly three and one half times that of water. Its attraction for bodies at its surface is about one sixth that of the Earth. A body weighing 200 pounds here would weigh about 34 pounds on the Moon.

It has no atmosphere, or at least, if any, but the veriest ghost of one. It is for this reason that the details of the lunar surface are so clear-cut when viewed through a telescope, and that the shadows are so intensely black. Except where the sunlight strikes direct—there is *no light*. To step into a shadow on the Moon would be to disappear.

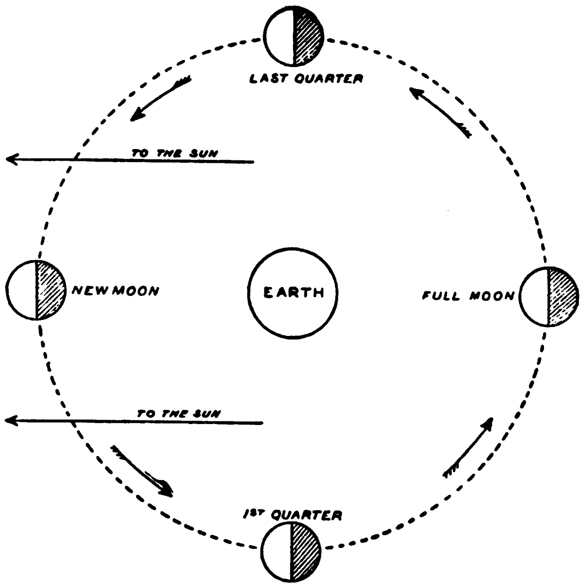
The lack of an atmosphere means that there is no lunar "weather." There is never any rain; in fact there is no liquid water on the Moon. There is no wind. There are no unexpected changes in temperature.

The amount of light and heat received from the Sun is about the same as intercepted by the Earth. The Moon, however, having no atmosphere, radiates away its heat almost as soon as it is received. It seems probable that the surface is very hot during the lunar day, and it is inevitable that, during the lunar night, the surface temperature drops appallingly low—almost to the absolute cold of space.

The reflective power of the Moon's surface is not high, in spite of its apparent brilliance when full. It throws back only about 17 per cent. of the light striking it. If the sky were *covered* with full moons we should receive from them only about one eighth part of the light we get from the Sun.

The Moon reflects to us a certain amount of heat; so small is this, however, that it requires the most delicate instruments even to demonstrate this fact. The amount has never been accurately measured.

The phases of the Moon were probably among the first celestial phenomena to be noticed by man. Since the Moon is an opaque body, and shines by *reflected* light only, we can see but that part which is illuminated and at the same time turned toward us. When the Moon is between us and the Sun (*see diagram*) its dark side is turned toward us and is entirely invisible. This is at the time of the "new moon." About a week later half of the illuminated hemisphere is visible. This is "first quarter." "Last quarter" occurs about one week after full moon, the other half of the Earthward hemisphere being illuminated then. When the Moon is on the other side of the Earth from the Sun it presents to us the full



THE PHASES OF THE MOON

As the Moon swings around the Earth as shown by the small arrows, the Sun being in the direction indicated by the long arrows, it is evident that, at "new moon," the dark side of the Moon will be turned to the Earth, and as the satellite's revolution continues an increasing portion of the illuminated hemisphere will be seen, until at "full moon" the whole of it is presented to us. From "full" to "new" a corresponding decrease occurs illuminated hemisphere. Between the periods of new moon and first quarter (or half moon, as it is popularly called) we see illuminated less than half of a hemisphere and we have then a "crescent" moon. Between the half moon and the full we see more than half the illuminated hemisphere and have the "gibbous" moon. The line between the illuminated and dark hemispheres is called the "terminator."

Mercury and Venus have just such phases, for the same reason. There is this difference however. When the Moon is at "full" *we* are between it and the Sun; when Mercury or Venus show "full" the Sun is between us and them. Viewed from the Moon, the Earth would show phases also, being "full Earth" at the time of new moon, and "new Earth" at the time of full moon.

If the orbit of the Moon around the Earth were in the same plane as that of the Earth's revolution about the Sun we should have eclipses of the Sun every new moon and eclipses of the Moon every full moon. (For eclipses see Chapter XV.) The lunar orbit, however, is inclined to that of the Earth at a little more than 5 degrees. Therefore at "new" the Moon usually passes a little below or above the Sun, and at "full" above or below the shadow of the Earth.

There is a popular superstition that the Moon affects the weather, but the most careful study of records has failed to show any such connection. It is also believed that the full moon clears away clouds, but again scientific research does not disclose any such effect. Whether the difference of the Moon's distance from the Earth, caused by the former's elliptical orbit, actually affects the magnetic needle, as indeed it seems to do, is a question now being closely studied.

Near the time of new moon, the whole disk is easily seen, the part upon which the Sun does not shine being illuminated by a pale somewhat reddish light. This is popularly known as the "old moon in the new moon's arms." This light is reflected light from the Earth, or *Earth-shine.* As noted above, the Earth at that time, when viewed from the Moon, is nearly full. The ruddy color of the Earth-shine is caused by the light passing twice through our atmosphere. Leonardo da Vinci was the first man to explain this phenomenon satisfactorily.

The surface of the Moon is broken into great mountain ranges, enormous "craters," wide and deep cracks or "clefts," and innumerable smaller cracks or rills. The whole of its visible surface has been mapped and measured more carefully and accurately than that of the Earth, and over 30,000 craters have been counted on the Earthward hemisphere. The first map of the Moon was made in 1647. The height of the mountains is enormous in proportion to the size of the Moon, several being over 18,000 feet high. The craters vary in size from tiny pits to vast cavities over 100 miles in diameter. Many of the larger craters have great central mountain peaks rising from their floors, and many others show smaller craters within their boundaries. The lack of "weather" allows these crater walls and mountain peaks to remain most precipitous. On the Earth the "weather" would and does wear such to more gentle slopes.

The causes of this condition of the Moon's surface are not definitely known. It seems probable that they were volcanic forces which were able to accomplish so much more than on the Earth because of the much less weight of matter upon the Moon. There is some support to the theory that meteoric bombardment is partially responsible.

From some of the bright crater-mountains emanate, or rather apparently emanate, systems of bright ray streaks, extending in some cases nearly across a visible hemisphere of the Moon. These are seen only under high illumination, and show best at full moon. In the accompanying illustration, the greatest of these ray-systems, that with the crater Tycho as its center, is just beginning to show. It is these ray streaks of the Tycho system which give to the full moon an appearance somewhat like that of a peeled orange. No plausible and really satisfactory explanation of these ray systems has yet been put forward.

To Earth-dwellers the greatest value of the Moon is its influence upon the tides, which by their constant change flush our harbors and shores, and by their motion prevent a stagnation of the ocean certain to occur without them.

Observations of recent years are causing astronomers to waver from the opinion current during the past century, namely that the Moon is a dead, unchanging mass. Some well-known observers have gone so far as to state flatly that there are evident signs of a vegetation existing on the floors of some of the larger craters.

THE MOON, AT NINE AND THREE-QUARTER DAYS

Image inverted, as in astronomical telescope
Note the faint streaks radiating from Tycho, the almost circular crater in the upper part of the picture. The dark crater near the bottom of the photograph is Plato, where color-changes have been observed on the moon's surface
From a photograph taken at the Yerkes Observatory

It is certain that slight changes in shade do occur in some regions of the lunar surface, but the necessarily extreme rarity of what atmosphere the Moon may still retain seems, in the opinions of even the non-conservative astronomers, to place out of the question the existence of actual vegetation, even in the form of the most primitive mould.

That the Moon is not wholly dead, as far as surface change is concerned, seems almost probable. Certain small craters appear to show unstable shapes, as if there still stirred a faint volcanic activity.

CHAPTER VII

MARS

MARS is fourth planet in distance from the Sun, and next to the smallest in size, being larger only than Mercury.

Its mean diameter is 4230 miles, a little more than half that of the Earth. Its polar flattening is small. Its surface is about one quarter that of the Earth, and its volume about one seventh.

Its mean distance from the Sun is nearly 141,500,000 miles. Its orbit is the most eccentric of all the planets except Mercury, and its distance from the Sun varies between about 154,500,000 miles and 128,200,000 miles.

Its distance from the Earth varies between very nearly 35,000,000 miles and 248,000,000 miles.

The relation of the times of the revolutions of Mars and the Earth about the Sun are such that the Earth passes *between* Mars and the Sun only once every two years. It is only when the Earth comes between the Sun and Mars, when the latter is at its *nearest* point to the Sun, that the 35,000,000 miles minimum distance is reached. This is about every 15 years. When the Earth passes between the two when Mars is farthest from the Sun, the planet is about 61,000,000 miles away from us. It is at the times of these near approaches of Mars that the public interest in the planet is re-awakened by the heralded preparations in the observatories to take advantage of this best opportunity for observation.

Mars revolves about the Sun in very nearly 687 days. This is the year of Mars.

It rotates upon its axis in 24 hours 37 minutes and 22 seconds, giving it a day slightly longer than that of the Earth.

Its axis is inclined to the plane of its orbit nearly 25 degrees, somewhat more than that of the Earth. This means a very little greater range in the seasonal temperatures than the Earth undergoes. The length of the Martian year produces, of course, seasons *longer* proportionately than those of our planet.

Mars moves in its orbit around the Sun at a mean speed of 15 miles a second.

Its mass is just one ninth that of the Earth, and its density about three quarters. Its attraction for bodies at its surface is nearly two fifths that of the Earth; a body weighing 200 pounds would weigh but 80 on Mars.

Mars has an atmosphere about which there is much discussion. That it is less dense than ours is universally admitted. The question of whether there is water-vapor in this Martian air, and consequently liquid water on its surface, is the great point of dispute. It would seem that recent spectroscopic observations prove the affirmative side of the debate.

Mars receives from the Sun, on an average, less than half of the light and heat which strikes the Earth; when nearest the Sun about 52 per cent. and when farthest away about 36 per cent. It is also a question of dispute as to whether the mean temperature is sufficient to allow water to remain liquid. The apparent melting of the polar caps, spoken of later, would seem to prove that water can, and does, exist in a liquid condition.

Its reflective power is about twice that of Mercury and half again as great as that of the Moon. It casts back about 26 per cent. of the light falling upon it.

It shows no complete phases as do the interior planets, but, when at right angles with us and the Sun, it presents a gibbous phase like that of the Moon a few days before or after "full."

The orbit of Mars is inclined to that of the Earth at slightly less than two degrees. Viewed from Mars, the Earth "transits" the Sun, at intervals of from 75 to 100 years, as do Venus and Mercury seen from here.

Mars has two moons, both very small. Their sizes are not accurately known. The most powerful telescope cannot magnify them enough to allow ordinary measurement. Their sizes are estimated, from the amount of light they reflect, at from 5 to 30 miles in diameter. The outer one, Deimos, revolves in 30 hours 18 minutes, at a distance from the center of Mars of 14,700 miles, and the inner one, Phobos, in 7 hours 39 minutes, at a distance of 5900 miles from the center and only about 3800 miles from the surface. As Mars rotates in about 24½ hours Deimos is seen by the Martians, if there are such, to rise *very slowly* in the east and to pass with great leisure across the sky remaining above the horizon for about two days and a half at a time, and passing through its phases nearly twice in this period.

Phobos on the other hand, rises *in the west*, hurries across the sky, sets in the east, and rises again in the west about four hours later. Three times in the course of a Martian day does Phobos rise and set, also passing through its phases each crossing of the sky. It has been remarked that, to Martians, Phobos might serve as a fairly accurate time-piece. Its orbital speed is about 40 miles per minute.

The smaller satellite is unique as being the only one known which has a period of revolution less than the rotational period of its primary.

One of the results of the nearness of the satellites is that, from the surface of Mars, the inner one, Phobos, is not visible from above latitude 69° in either hemisphere. Mars being much smaller than the Earth, its surface curvature is greater, and the horizon of a Martian place, in consequence, smaller. It is readily shown that above the latitude mentioned, Phobos would never rise above the horizon, but circle constantly below the bulge of the planet. Deimos, the outer satellite, may be seen from nearly all points of Mars, not being hidden until latitude 82° is reached. Our own Moon is at such a distance from us, that it is, of course, visible from even our Poles.

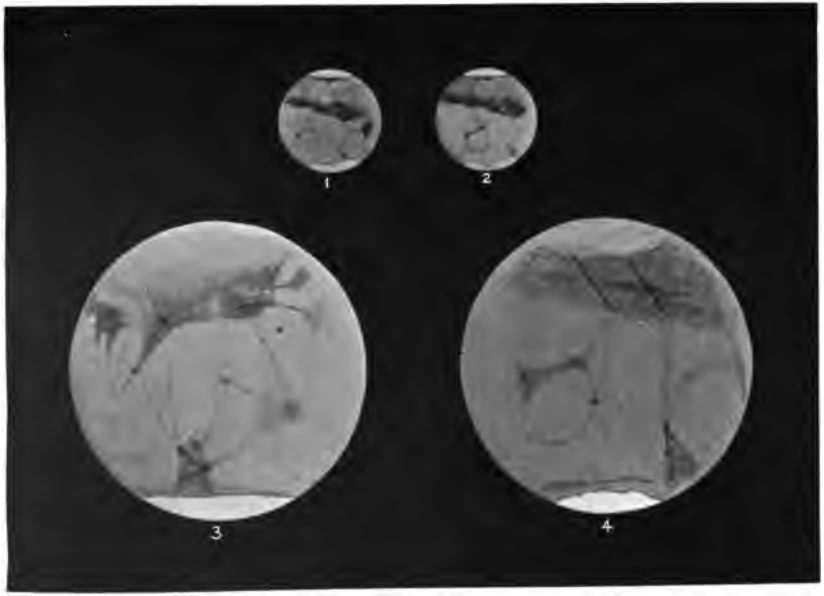
Frequent eclipses of the satellites also result from their propinquity to Mars; in some cases the moon passing into the shadow of the planet almost as soon as it has risen, and in many instances rising eclipsed. It has been calculated that the Sun may be eclipsed by Phobos about 1400 times a year. Naturally, because of the speed with which both the moons revolve, the duration of their eclipses is shorter than our eclipses.

The occultation, or eclipse, of Deimos by Phobos must occur about every ten hours when viewed from or near the Martian equator.

A still further peculiarity is that the moons, when in the zenith, must appear much larger than when on the horizon. Since the diameter of Mars is 4230 miles, Phobos, for example, is nearly one half again (2115 miles, or half the diameter) as far away when rising as it is when overhead, and consequently must, in mounting to the zenith, appear to grow nearly twice in area.

It is interesting to note that both Voltaire, in *Micromegas*, and Swift, in *Gulliver's Travels*, described Mars with two small moons; Swift even closely approximated their periods, much to the amusement of astronomers for years, until the discovery of the real satellites left the scientific world amazed at the accuracy of these wild guesses.

The surface of Mars, on the whole, has a characteristic reddish-ochre tint, and it is often referred to as the red, or ruddy, planet. Parts of its surface seem subject to change in color during its seasons, and that there is a real vegetation there is little doubted. Its poles are covered with white caps generally believed to be snow. It is from these caps that the "canals" seem to extend during the Martian summers when the caps decrease as if melting. The "canals" are very difficult to see, and appear only as extremely fine "hair-lines." Many observers still doubt their existence and believe them to be illusions of distance, others however, show maps of a complete network of them surrounding the whole planet. Through the courtesy of Professor Lowell, the writer has in his possession a print



MARS

1, 2 } Drawings by Prof. Lowell to accompany actual photographs of Mars showing many of the canals. Taken in 1907 by Mr. E. C. Slipher of the Lowell Observatory

3 Drawing by Prof. Lowell made January 6, 1914

4 Drawing by Prof. Lowell made January 21, 1914

Nos. 1 and 2 show the effect of the planet's rotation. Nos. 3 and 4 depict quite different sections. Note the change in the polar snow-caps in the last two

of an actual photograph of Mars made by Mr. E. C. Slipher in 1907. Since this photograph clearly shows some of the "canals," there can be no question that these lines do exist. It is most unfortunate that it is impossible to print a reproduction of this photograph. The detail is so delicate that no process except a photographic print made from a negative can show it satisfactorily. The upper two drawings in the accompanying illustration were made by Professor Lowell for close comparison with the photograph, which indeed shows more detail than the drawings. Professor Lowell insists that what is seen is the vegetation flanking the piping of a vast irrigation system which taps the melting polar snow-caps, the whole planned and managed by intelligent beings to make the best use of a weak and failing water supply.

The question of the possibility of life on Mars rests mainly on two things; the temperature and water. If the temperature is too low to allow water to remain liquid, life, as we know it, cannot exist. The temperature is by all estimates close to this critical point. If there is no water at all or practically none—as some astronomers believe—life could not exist. It would seem now that, except for the ultra-conservative astronomers, the authorities agree that water does exist in a free and liquid state during the proper seasons, so that at least a primitive form of life can be supported. It is not improbable that by the time of the next *nearest* approach of Mars, in 1924, improved observational aids will settle the disputed questions.

Much has been written upon this great Martian question. Professor Lowell's books are the most noted. A small volume by Maunder (*Are the Planets Inhabited?*) gives an interesting presentation of negative opinions.

CHAPTER VIII

THE ASTEROIDS

THE Asteroids are a multitude of very small planets revolving about the Sun between the orbits of Mars and Jupiter.

Their diameters range from probably a few yards up to about 500 miles. Their surfaces and volumes of course range accordingly.

Their mean distances differ very much,—from about 135,500,000 miles to over 400,000,000 miles.

Their distances from the Earth vary from 13,500,000 miles to 500,000,000 miles.

Their periods of revolution range from 687 days to about 9 years.

Of their rotations nothing at all definite is known.

The *average* inclination of their orbits to the plane of the Earth is nearly 8 degrees. The orbit of one is inclined nearly 35 degrees. Their orbits are all very eccentric. Their speeds in their orbits vary with their distances from the Sun.

Of the individual masses and densities of the majority nothing is known. From their tiny size it is certain, however, that their attraction for bodies on their surfaces must be very slight. A man on the largest one could probably with ease throw a stone with a speed sufficient to carry it away forever from the little planet. It is estimated that their *aggregate mass* cannot exceed ¼ that of the Earth. It may be as low as $\frac{1}{100}$ that of the Earth.

They can certainly have no atmospheres.

The Asteroids are numbered in the order of their discovery, and all but those lately found bear names also, such as: Ceres (1), Eros (433), Pallas (2). Ceres, the first and largest, diameter about 485 miles, was discovered in 1801, and the succeeding three within the next few years. Then none were found until 1845. From that date, their known number has increased rapidly, photography lending most efficient aid, until now over 800 are listed; and there are unquestionably many more.

They are probably of irregular shape and reflective power, the variations in the light of some of them making this deduction sound.

Vesta (4), though third in size, is the only one seen by the naked eye, as a barely visible speck of light; and this only under favorable circumstances.

One of these little planets, Eros (433), is of particular interest. This "worldlet" approaches the Earth at times nearer than any other celestial body except the Moon, meteors, and possible comets; its least distance is 13,500,000 miles. These near approaches unfortunately are very rare, because of the relations of its orbit and revolution to those of the Earth. The next one will not occur until 1938.

The value of the proximity of Eros lies in the opportunity given to use it in determining with still greater accuracy the distance of the Earth from the Sun.

Eros is the nearest of the Asteroids to the Sun, and revolves about it in 687 days, nearly the same as Mars, at a mean distance of 135,480,000 miles. Its orbit like that of the others is very eccentric, and its distance from the Sun varies between 166,000,000 miles when farthest away and 105,200,000 miles when nearest.

It is too small to be measured with any degree of accuracy, but its diameter is believed to be about 20 miles.

There is a *periodic* variation in its light which leads to the probably sound deduction that it rotates on its axis in about 5½ hours.

Its orbit is inclined to that of the Earth at nearly eleven degrees.

The largest four of the Asteroids are, in the order of their discovery:

Ceres (1)	Diameter	about	480	miles
Pallas (2)	"	"	300	"
Juno (3)	"	"	120	"
Vesta (4) (The brightest)	"	"	240	"

It is improbable that any of the others, either those now known or those yet undiscovered, can be more than 50 to 60 miles in diameter.

CHAPTER IX

JUPITER

JUPITER, the giant of the planets, is the fifth in order from the Sun.

Its mean diameter is 86,500 miles, or over ten times that of the Earth. Its polar flattening is great, and the disk in a telescope shows distinctly oval. The equatorial diameter is about 88,400 miles, and the polar diameter only about 83,000. Its surface is the vast amount of 22,480,000,000 square miles, and its volume the inconceivable amount of 338,000,000,000,000 cubic miles, respectively 119 times and 1300 times the surface and volume of the Earth. It is greater than all the other planets rolled into one.

Its mean distance from the Sun is 483,000,000 miles. Its orbit is considerably more elliptical than that of the Earth, and Jupiter's solar distance varies from about 462,000,000 miles to over 500,000,000.

Its distance from the Earth, when nearest, is approximately 370,000,000 miles, and, when farthest away, nearly 600,000,000 miles. Its *average* nearest and farthest distances during the year are, however, about 390,000,000 miles and 580,000,000 miles.

Jupiter revolves about the Sun in 11 years, 10 months, and 17 days.

It rotates on its axis more swiftly than any of the other planets. Its time of rotation is about 9 hours 55 minutes. This time can be given only approximately, because, like the Sun, Jupiter's surface rotates faster at the equator than near the poles. This rapid rotation carries a point on the equator of the planet at a speed of nearly 26,000 miles an hour, a spot on the Earth's equator traveling slightly more than 1000 miles an hour. This short day of Jupiter makes its year include 10,455 of them.

The axis of Jupiter is almost perpendicular to the plane of its orbit, the inclination being only 3 degrees, so it, too, has no seasons as we know them.

Its mean speed in its orbit is about 8 miles a second.

Its mass is slightly more than 316 times that of the Earth, but its density is much less, being scarcely one fourth. The *average* attraction for bodies at its surface is nearly 2⅔ times that of our planet, but, because of the rapid rotation and the consequent high centrifugal force, this attraction varies almost 20 per cent. between the poles and the equator. A body weighing here 200 pounds would weigh at Jupiter's equator about 500 pounds, and at one of his poles about 600 pounds.

It has a very extensive atmosphere, and it is probable that nearly all the surface markings we see with a telescope on Jupiter are *atmospheric*, and not on the true surface of the planet. For that matter, it is very doubtful whether there is anything solid about it. It would seem to be a ball of almost liquid consistency surrounded by clouds and vapor.

It receives, when nearest the Sun, about one third as much light and heat as does the Earth; about two fifths as much when farthest away.

The reflecting power of the planet is high. It sends back 62 per cent. of the light received.

Jupiter shows no phases, being too far outside our orbit.

Its orbit is inclined to the Earth's less than any other planet's except Neptune's, the inclination being barely more than 1¼ degrees.

MOONS

Jupiter has eight moons which have been discovered. The method of searching by photography is so nearly perfect now that it is extremely doubtful that more will be found.

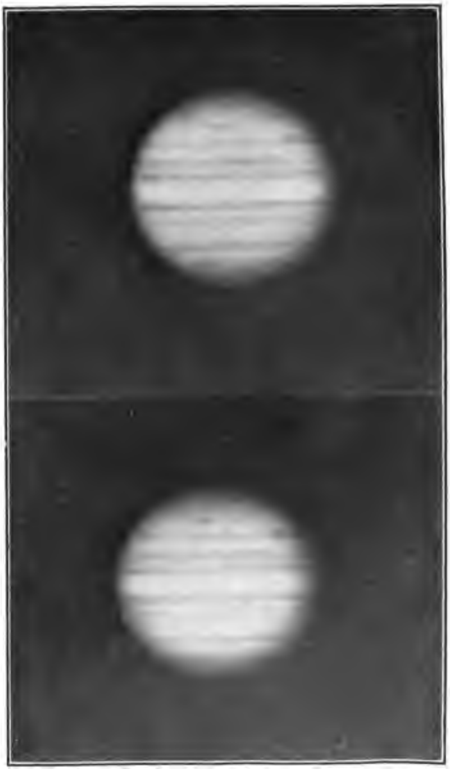
The moons are usually known by Roman numerals. The original four bear names also. Their dimensions, orbital times, and distances from them are:

Name or Number	Mean Dist. from Jup.	Periods of Revol. days hrs. min. sec.	Diameter in miles
V	112,500	0 11 57 27	?(very small)
I (Io)	261,000	1 18 27 36	2500
II (Europa)	415,000	3 13 17 54	2100
III (Ganymede)	664,000	7 3 59 35	3560
IV (Calypso)	1,167,000	16 18 5 7	2960
VI	7,100,000	8½ months	?(very small)
VII	7,400,000	9 "	? " "
VIII	16,000,000	26 "	? " "

It will be seen that the system is enormous.

These moons apparently always turn the same side to Jupiter.

Their orbital speeds vary according to their



JUPITER, 1910

Note the distinctly oval form of the planet and the "belts"
From a photograph taken at the Lowell Observatory

distances from their primary. The nearest traveling at about 15 miles per second, the farthest at about 1.3 miles per second.

Their reflective power varies and there seems a slight difference in color.

Their orbits are nearly circular, and those of the inner ones are almost in the plane of the planet's equator.

The orbits of the outer ones are inclined at over 30 degrees. The larger ones seem to have some atmosphere.

To the telescopist with a small instrument these moons are of great interest. The changes in position due to their revolutions can be detected in but a few minutes' observation, and their transits, as they pass directly between Jupiter and the Earth, their occultations as they pass behind him, and their eclipses as they disappear in his shadow, are among the most easily observed celestial phenomena.

It was through the discrepancy between the predicted and observed times of the eclipses of these moons that it became known that light required time to travel.

Only four of these moons may be seen except by the aid of the great telescopes. There have been partially substantiated cases of these four being seen with the naked eye. These moons offer added interest as being the first celestial objects discovered by Galileo with the first telescopic aid.

The physical condition of Jupiter is unquestionably liquid or plastic. As stated, the markings seen are almost certainly atmospheric ones, where great "trade winds" appear as the dark bands or "belts" which characterize the planet. Great semi-permanent markings, such as the famous Great Red Spot, break out from time to time, but the invariable fading of such demonstrates that, almost certainly, we do not view a solid surface. In the larger telescopes the bands, and, in fact, all the surface show a wonderful range of detail and color.

It is suggested that Jupiter is still hot enough to give forth a light of its own. This is doubtful, but there is no doubt that it still is very hot.

Life on Jupiter itself is at present entirely out of the question, but there is a very doubtful possibility of such existing upon some of the larger moons. However, at that tremendous distance from the Sun, it would seem necessary for Jupiter to be hotter than is now supposed, if the planet is to radiate to them enough heat to compensate for the feebleness of the solar rays at that distance, and maintain a temperature sufficiently high to support life.

Jupiter, when viewed from the Earth, with the naked eye, shines almost as brilliantly as Venus, and because of its comparatively slow orbital motion, remains for months each year as a splendid morning or evening star.

CHAPTER X

SATURN

SATURN is the second largest of the planets, and is the sixth in distance from the Sun.

Its mean diameter is about 73,000 miles, more than 9 times that of the Earth. The polar flattening is very great, nearly $\frac{1}{10}$, and its polar diameter is only 68,000 miles, while its equatorial diameter is about 75,000 miles. Its surface is about 84 times that of the Earth, and its volume 770 times.

Its mean distance from the Sun is approximately 886,000,000 miles, or 9½ times as much as the Earth's. The eccentricity of its orbit is considerable, and, in consequence, the variation in its solar distance is nearly 100,000,000 miles.

Its distance from the Earth ranges from 774,000,000 miles, when at its nearest, to 1,028,000,000 miles, when farthest away.

It revolves about the Sun in about 29½ years.

Its rotation upon its axis is almost as swift as that of Jupiter, being nearly 10 hours 14½ minutes. It is the speed of this rotation, combined with the small density of the planet, that causes the great distortion of its shape.

Its axis is inclined to the plane of its orbit nearly 27 degrees, or more than the Earth's. This produces seasons as we know them.

Saturn moves in its orbit around the Sun at a mean speed of 6 miles a second.

The density of this great planet is surprisingly small. It has been very accurately figured and proves to be only about one eighth that of the Earth or *less than that of water*. Saturn would float comfortably in an ocean great enough to hold it. The mass is about 95 times that of the Earth, and less than one third that of Jupiter. Its mean attraction for bodies at its surface is therefore, in spite of its great size, only about 1.2 times that of the Earth. At the equator, because of the great centrifugal force counteracting the force of gravity, it is *less than* that of the Earth. The variation between its attraction at its poles and at its equator is nearly 25 per cent.

Saturn has an atmosphere apparently much like that of Jupiter, and, as we see in a telescope, similar bands and belts. It shows, at each pole, moreover, curious caps of faint olive green. These caps are not constant, but are usually visible. Just what they are is not known.

It receives from the Sun on the average only about $\frac{1}{100}$ as much light and heat as the Earth. This amount varies, of course, with its distance from the Sun, but it is always pitifully small.

Its reflective power is high, being about that of Venus. It throws back about 72 per cent. of the light received.

It is too far beyond the orbit of the Earth to show phases.

The orbit of Saturn is inclined to that of the Earth about two and one half degrees.

RINGS

Saturn is unique in the Solar System in the possession of a series of vast encircling rings which lie in the plane of its rotation. Because of the inclination of Saturn's axis to the plane of its orbit, it sometimes presents one pole and then the other to the Sun, as does the Earth. The latter, compared to Saturn, is so near the Sun that we view the planet almost as if we were on the Sun itself. The result is that we, at

SATURN

December 23, 1912. Note the dark cap, the belts, the divisions in the rings, and the oval form of the planet

From a photograph by E. C. Slipher, taken at the Lowell Observatory

times, see the north surface of the rings, and, about fifteen years later (one half of Saturn's time of revolution about the Sun) the south surface, while half way between we see them presented *edgewise*, when they are visible only through the most powerful telescopes, and appear as a sort of luminous needle running through the planet. It is because of this change in appearance, as seen from the Earth, that Galileo only nearly discovered them. He saw them when he first turned his telescope on Saturn, but as the planet was approaching the position when the rings disappear he saw them but faintly, and then seemed to see them gradually vanish. This gave him the impression that they were illusionary, and, in disgust, he never studied the planet again. In 1655, Huyghens discovered their real existence and shape.

There are three concentric rings in all. The outer one has a diameter of about 173,000 miles. Its breadth is about 10,000 miles. There is a division space of about 1000 miles between that and the next. The second ring is quite the broadest, being nearly 17,000 across. The third is called the "crêpe ring" from its dusky appearance. It is only visible in the great telescopes. It is semi-transparent. Between the inner edge of the third ring and the surface of the planet is a space of about 9000 miles.

These rings are extremely thin in proportion to their diameters, the paper upon which this is printed is thicker in proportion to its size than they are. The thickness of the rings is estimated at about 100 miles.

The rings were first considered solid. It has now been demonstrated that they must be composed of countless tiny "moonlets," possibly only infinitely small particles, each pursuing its own orbit about the planet. When the rings are seen edgewise there appear certain thickenings or knots as if clusters of these particles had formed.

It has not been settled whether these rings are a permanency or whether they will eventually be dispersed. Recently an extremely faint outer ring has been observed similar to the "crêpe" ring. This would seem to suggest almost the probability of an eventual breaking up of this marvelous system, these two "crêpe" rings being possibly the beginning of the disintegration.

MOONS

Saturn, of all of the planets, possesses the greatest retinue of satellites. No less than ten moons are now known to encircle it. Their dimensions, orbital times, and distances from the planet are:

	Mean Dist. fr. Saturn	Periods of Revol.			Diameters in miles.
		days	hrs.	min.	
I. Mimas	117,000		22	36	600
II. Enceladus	157,000	1	8	54	800
III. Tethys	186,000	1	21	18	1,100
IV. Dione	238,000	2	17	42	1,200
V. Rhea	332,000	4	12	30	1,500
VI. Titan	771,000	15	23	18	3,500
X. Themis	906,000	20	20(?)	0	30(?)
VII. Hyperion	943,000	21	7	36	500
VIII. Japetus	2,225,000	79	21	6	2,000
IX. Phœbe	8,000,000	580	2	54	40(?)

As in the case with Jupiter, it will be seen that the size of the system is enormous. Japetus has a period of nearly that of Mercury while the revolution of Phœbe requires over eighteen months.

Japetus shows a distinct difference in brilliancy during its orbit, being always brighter when west of the planet than when east of it. This shows that it follows the general rule of satellites and turns always the same side to its primary—one half of its surface having a higher reflecting power than the other.

The motion of Phœbe is unique—its revolution is *retrograde*, that is, opposite to the rotation of its primary. Prof. W. H. Pickering, the discoverer, suggests two possible explanations for this. One is "that Phœbe was originally simply a comet which was captured by Saturn. In that case, if the comet passed on one side of Saturn, its orbital motion would be direct, if on the other, retrograde." The other is "that at the remote time when it [Phœbe] was formed, and when the mass of Saturn filled the whole orbit of its satellite, Saturn was then revolving in a retrograde direction. During the ages that elapsed before the next satellite, Japetus, came into existence, Saturn had changed the plane of its rotation [or turned over part way, (compare with the theory regarding Uranus and Neptune in the following chapters)] so that the satellite's motion was direct."

Themis, the latest addition to the family, is hopelessly beyond the range of direct vision with even the greatest of our telescopes. It, like Phœbe, was discovered by photography.

The orbits of the five inner satellites are almost circular; those of the outer ones are much more elliptical. Japetus and Phœbe have orbits inclined to the plane of the rings about ten degrees and six degrees respectively. The other satellites all move almost exactly in the plane of the rings. The orbital speed of the moons ranges from about 9 miles per second for the inner one to about one mile a second for the outermost.

It is not improbable that, in the great gap between Titan and Japetus, other satellites beside Hyperion and Themis may be discovered. Such, however, must be extremely small.

Saturn was the outermost planet known to the ancients, and shines as a bright star with a steady golden light.

Like Jupiter it is probably very hot. There has been some question whether Saturn, too, shines partly by its own light, but this seems decided in the negative. That there is no *solid* matter in its composition is certain, the planet's low density and great equatorial bulge put that beyond doubt.

The surface markings seen in a telescope, are without doubt, like those of Jupiter, merely atmospheric; great trade winds of dense vapors,—the similarity between the two planets being great.

Life on Saturn is impossible, as we know life, and that its moons could support such seems most improbable. Unless Saturn radiates far more heat than appears reasonable, the moons must be frozen, dead globes.

To the "sight-seer" through a telescope, Saturn and his system proves a most surprisingly interesting and beautiful sight.

Note.—Dr. Percival Lowell has just shown the author some marvellous photographs of the inner satellites of Saturn. These photographs, taken recently at the Lowell Observatory, clearly prove that Tethys and Dione vary regularly in brilliancy, according to their orbital positions; demonstrating that they, too, turn always the same face to the planet.

CHAPTER XI

URANUS

URANUS is the fourth from largest of the planets, and is the seventh in order from the Sun.

Its mean diameter is somewhat in question being estimated from 28,500 to 35,000 miles. Probably about 32,000 miles is nearly correct. Its surface is roughly sixteen times that of the Earth, and its volume about 65 times. It shows a distinctly oval disk, the ellipticity being about one fourteenth of the diameter.

Its mean distance from the Sun is about 19 times that of the Earth, or nearly 1,800,000,000 miles. Its orbit is not quite so elliptical as that of Jupiter, but its distance from the Sun varies about 70,000,000 miles in the course of one revolution.

Its mean distance from the Earth varies between about 1,893,00,000 miles and 1,707,000,000 miles.

It revolves about the Sun in slightly over 84 years.

Its time of rotation upon its axis is not known, owing both to its great distance of its peculiar axial inclination, and a lack of definite spots or separated markings upon its surface.

Its axis is inclined to the plane of its orbit to such a degree that Uranus may be compared to a top *rolling on its side*, not standing on its point. This is not definitely agreed upon but seems logical since we look at the revolution of its satellites not as with the inner planets—edge on—but as if we were watching a wheel revolve, the axis being pointed at us; and practically all satellites revolve fairly close to the plane of the rotation of their primary.

Uranus moves in its orbit with the slow planetary speed of about 4⅕ miles per second.

Its mass is 14½ times that of the Earth, but its density only slightly more than one fifth. Its attraction therefore for bodies at its surface is, in spite of its size, somewhat less than the Earth's. A body weighing 200 lbs. here would weigh upon Uranus about 180 lbs.

It has an extensive atmosphere which the spectroscope tells us contains some substance not yet identified on the Earth. It is probably this substance which accounts for the distinct greenish tinge of the planet's light.

It receives from the Sun on an average of barely more than $\frac{1}{300}$ of the light and heat reaching the Earth.

Its reflective power is high, somewhat more than Jupiter's. It sends back 64 per cent. of the light striking it.

It, of course, shows no phases.

Its orbit lies almost in the plane of the Earth's, more nearly so than that of any other planet.

MOONS

	Dist. from Planet	Periods of Revol.			Diameter (*Est. only*)
		day	hour	min.	
Ariel	120,000	2	12	30	600
Umbriel	167,000	4	3	30	500
Titania	293,000	8	16	50	1200
Oberon	365,000	13	11	6	1000

It has been considered that they revolve backwards like the ninth satellite of Saturn. It is now almost certain that they revolve forward; that is in the same direction as the planet rotates. This has been open to question, as explained in the last paragraph of this chapter.

Uranus was the first planet ever *discovered.* All the others have been known since history began. It was found accidently by Sir William Herschel, in 1781, while "sweeping" the heavens for what he might find with a telescope of his own manufacture. At first, though seeing immediately that it was not a star, its true nature did not occur to him. For some time it was studied as a comet, and not until almost a year later was it recognized as a new planet.

It shines as a faint star, of greenish tint, just visible to good eyes under clear conditions.

It shows faint bands or "belts" like those on Jupiter or Saturn.

The inclination of the axis of Uranus is not entirely agreed upon. If it is *less* than 90 degrees, the satellites have retrograde revolutions, but if *more* than 90 degrees the satellites revolve direct. This would seem more logical. Professor Lowell believes that Uranus will, through the course of ages, turn over (as will a gyroscope when rotated one way and swung in the opposite direction), until its axis is eventually perpendicular to the plane of its orbit; that it started in an inverted position and has not quite reached the half-way mark in its attempt to conform to the proper planetary behavior. His theory is not universally accepted, but it is the most logical explanation of the curious position of Uranus, and also of that of Neptune. This idea is in accord with one of the explanations Professor Pickering gives for the retrograde revolution of Saturn's outermost satellite.

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CHAPTER XII

NEPTUNE

As far as is now known, Neptune is at the frontier of the Solar System. It is the third from the largest of the planets and the eighth in distance from the Sun.

Its diameter is somewhat more than that of Uranus, being probably about 33,000 to 34,000 miles. Some measurements make it as low as 28,500. Its surface is about 19 times that of the Earth and its volume 85 to 90 times. It shows no measurable polar flattening.

Its mean distance from the Sun is 2,800,000,000 miles, and even though the planet's orbit is nearly circular, the diameter of its orbit is so great that even a small ellipticity varies its distance from the Sun nearly 50,000,000 miles during a revolution.

Neptune requires 164 of our years to make one revolution about the Sun.

The rotation time is in doubt. It is even more difficult to measure than that of Uranus. Neptune probably rotates somewhat slower than the latter. The density of these two planets is about the same, and, while Uranus shows a "bulge" at its equator, due to the centrifugal force of rotation, Neptune, as said above, does not show enough to measure. Its rotation is usually spoken of as retrograde, or backward.

Its axis is inclined to the plane of its orbit either 35 degrees or 125 degrees. If the former, the reason for the retrograde rotation is difficult to explain, if the latter, Professor Lowell's theory may fit the case. With Neptune he believes that, owing to its much greater distance from the Sun, its slower orbital speed, as well as probably slower rotation than Uranus, the effort to "right itself" is much more feeble, and will take longer time. But, like Uranus, it is doing its best to turn over, and so conform to the general custom of properly behaved planets by rotating the right way round. As mentioned before, this theory is not generally accepted. It certainly is logical, however, and gives an explanation of a fact for which as yet no other apparently sound reason has been advanced.

Neptune, being the farthest away from the

Sun, moves more slowly than any of the planets, its orbital speed being only about 3½ miles per second.

Its mass is about 17 times that of the Earth, but its density only about one fifth. Its attraction for bodies at its surface, therefore, is less than that of the Earth, and slightly more than that of Venus. A body weighing 200 lbs. here would on Neptune weigh about 175 lbs.

It has a very extensive atmosphere. The more carefully this is studied the farther it is found to reach.

Neptune receives from the Sun only a wretchedly small proportionate share of light and heat, about $\frac{1}{1000}$ of that which warms and illuminates the Earth. Unless, therefore, the planet be still intrinsically hot its temperature must be low beyond description. Do not think, however, that there is no real daylight on Neptune. The Sun, though appearing so small as not to be seen as a real disk by the naked eye nevertheless gives as much light as about 700 of our full moons. "As seen from Neptune, the Sun would look like a brilliant electric arc-lamp at a distance of a few yards."

The reflective power of the planet is less than that of Saturn. It throws back somewhat more than half the light received.

It shows no phases.

Its orbit is inclined to that of the Earth about one and three quarters degrees.

Neptune, like the Earth, has apparently only one moon. This is as yet unnamed. Its diameter is estimated, by measuring the light it reflects, as about 2000 miles, or nearly the size of our own Moon.

The satellite's distance from the planet is also about the same as the Moon's from us—223,000 miles.

It revolves about Neptune in 5 days 21 hours, and moves as Neptune rotates—that is, in an apparently backward direction.

Of its rotation nothing is known. Presumably like most moons it always presents the same side to its primary.

Its orbit, like most satellites, lies close to the plane of the planet's equator.

It is visible only in large telescopes, and is a difficult object to see.

It was discovered within a month of the discovery of Neptune itself.

Neptune's discovery in 1846 marked the great triumph of mathematical astronomy. Uranus had failed to move in its orbit precisely as predicted, and astronomers were at a loss to explain the fault. The difference between the predicted and the actual positions was extremely slight from a naked eye view-point, but that there were differences showed that something was wrong. Two men, Adams of England, and Leverrier of France, independently took up the solution of the problem, and not only each arrived at the conclusion that a planet exterior to Uranus was causing the perturbations of the latter, but each computed this hypothetical planet's position with amazing accuracy. The observatory to which Leverrier sent his calculations was the first to recognize the planet within but a very short distance of where its position had been figured. For many years Adams was not given due credit for his marvelous labor, since, though his calculations were completed months before those of Leverrier, the Astronomer Royal of England, to whom Adams sent his figures, was too methodical a man to take up the search for this supposed planet until it was too late to be first. It may be said that the two men, Adams and Leverrier fairly divide the great honor.

The surface of Neptune shows practically no markings except a faint suggestion of a band or "belt" similar to those of the other larger planets. Its light seems to have a faint tinge of the same green shown by Uranus.

It will be noticed that Neptune and Uranus are much alike in many respects; as also are the Earth and Venus.

Life on Neptune seems, of course, utterly beyond possibility.

CHAPTER XIII

COMETS

COMETS are the "fiery-haired" stars of the ancients, the word comet being derived from the Greek κομήτης (long-haired). From time immemorial, they have been regarded by the ignorant as portents of evil, presaging the fall of empires, the death of kings, the coming of pestilence, the approach of war, etc. Science, in proving the fallacy of such ideas, has rendered a great benefit to mankind.

Comets may be divided into several classes:

Naked-eye comets and *telescopic comets*, of which the latter are by far the more numerous. It is size rather than distance from the Earth that determines the inclusion of a comet in one group or in the other.

Periodic comets and *parabolic or hyperbolic comets*. Here the difference is in the apparent shape of the orbit. Periodic comets revolve about the Sun in elliptical orbits, as do the planets, but in ellipses of great eccentricity, or elongation. Parabolic and hyperbolic comets are those which *apparently* (note the apparently) pass the Sun in curves that are not *closed*, that is in curves which never return upon themselves, and which would therefore allow a comet following such a curve to pass the Sun *but once*. It is an open question whether any comet moves in such an orbit. None are known certainly to do so; many are known to move in ellipses; no authority will express absolute belief in the parabolic or hyperbolic orbit, and several are willing to state definitely that such an orbit does not exist. The balance seems, therefore, to be against the "open" orbit and in favor of the eventual return of all comets, unless they are destroyed or disintegrate. The reason this question is so difficult to decide is that the total path of a celestial body may be constructed only by measuring and plotting the curve of that part of the path visible to us. In the large cometary orbits this is so small proportionately that it is almost impossible to decide whether we have seen part of a tremendously eccentric, or elongated ellipse, or part of a parabola or hyperbola.

Short-period and *Long-period* comets. In this case the difference is only in the time of revolution about the Sun. This time varies from two or three years up to several thousands and if the apparent parabolic comets are indeed periodic, up to perhaps scores of thousands.

A comet is usually composed of three main parts; the *nucleus*, the *coma*, and the *tail*.

The nucleus is a bright star-like point of light, which under a telescope shows an ill-defined disk. In large comets it is sometimes many hundreds or even many thousands of miles in diameter.

The coma is a foggy mass surrounding the nucleus. The two together look like a star shining through a haze. They comprise the *head* of the comet.

The tail, when such exists, is an extension of the coma. This sometimes is many *millions* of miles in length. It always points away from the Sun.

Comets are almost certainly composed of gases and *close* swarms of meteors, "or small detached masses of matter. These masses are so small and so numerous that they look like a cloud, and the light which they reflect to our eyes has the

COMET MOREHOUSE, 1908

Note the marked changes in the tail. The short bright lines are the elongated images of stars, the camera being adjusted to follow the motion of the comet

Photographs from the Yerkes Observatory; taken three hours apart

milky appearance peculiar to a comet. On this theory, a telescopic comet without a nucleus is simply a cloud of these minute bodies. The nucleus of the bright comets may either be a more condensed mass of such bodies, or it may be a solid or liquid body itself."—(Newcomb). The tail is not a permanent appendage, but forms as described below.

When the comet is far from the Sun, it shows no tail and often no nucleus, and appears only as a patch of cloudy light. As it approaches the Sun, it grows brighter and a nucleus generally forms at its brightest point. Then the coma begins to extend away from the Sun and lengthens gradually and slowly at first, into the tail. In bright comets, *envelopes* or bows of light form about the nucleus on the side *toward* the Sun, and extend to mingle with the tail. As the comet passes from the Sun on its outward journey, these changes occur in reverse order, and the comet reverts to a hazy patch of milky light which gradually is lost to view.

Part of the light of a comet is that of the Sun reflected, but comets are self-luminous when near the latter. What causes the action among the particles composing a comet's head to produce this light is not definitely known. It certainly is connected in some way with the solar influence, and may be the effect of heat or of some electrical action, or may be the result of the Sun's gravitational perturbations among the particles of the head, causing them to collide with each other and fuse into gases, or at least to glow from the heat of the collisions. It is probably occasioned by a combination of all these factors. The actual *light* of the Sun may have effect, as it apparently has in connection with the formation of the tail.

The tail is supposedly formed by the repelling action of the light of the Sun upon the tiny particles of matter in the coma. It has been demonstrated that light does exert a physical force of this kind. On large bodies this pressure of light has no appreciable effect, as they are held by the greater power of the force of gravitation. Gravitation acts on the *mass* of a body while a pressure acts on the *surface* of a body. Decrease the size of a body and the mass decreases as the cube while the surface decreases only as the square. It is possible, therefore, to reach a size of body small enough that the power of the light pressure will be greater than that of the gravitational pull. It is of particles of this very tiny size that the tail of a comet is composed, and they are therefore, driven away from the Sun by its light in spite of the effort of gravity to pull them to the Sun. It is probable that these particles never rejoin the comet's head and are left in space scattered along the comet's orbit. Many of the smaller comets never develop a tail.

The mass of comets is relatively very small. Stars shine through all parts of them, including the nucleus at times; and through the tail with certainly no appreciable diminution of light. This shows a great lack of density. The tails of comets are certainly extremely rarefied, probably more so than the nearest approach to a vacuum possible to obtain on the Earth. Several times, indeed, the Earth has passed through a comet's tail without our recognizing the fact from any change in conditions,—except possibly a faint luminosity of the atmosphere. This happened in the case of Halley's comet in 1910.

Prophecies are often heard of the dire fate certain to befall the Earth through cometary collision. In the first place, the mathematical chance of such a collision is once in about 15,000,000 years, and in the second place it is not at all certain that we should suffer more than from a great meteoric shower,—the harmful effects of which are nil. If the particles forming the head and particularly the nucleus of a large comet should strike the Earth squarely, there would probably be some local damage in the direct line of the collision, but this only if these particles were of large enough size to get through our air without being dissipated by the great heat of the friction. As a matter of fact, the Earth several times a year does meet the *remains* of comets in the shape of meteor swarms, and the contact is noticed by no one except the diligent "star-gazer."

Regarding the origin of comets there has been much theorizing. It seems probable that they are, like the meteors, described in the next chapter, uncollected fragments of the once great parent body, shattered to pieces in the past ages, from whose parts the members of the Solar System, including the Sun, were formed.

Comets differ from the great bodies of the System in their lack of permanence. They break up, causing the "remains" of which we have just spoken.

The one known as Biela's comet was seen in 1846 to split in two, depart from the Sun with two heads, and return in 1852 widely separated! Since then it has not been seen, but in 1872 there was a meteor shower just as the Earth was passing the track of the lost comet, these meteors unquestionably being part of what was left of it.

There is a certain curious relation between the orbits of about 30 comets and that of the mighty planet Jupiter, and it is evident that the planet is responsible for the paths of the comets, having pulled them out of greater orbits by his gravitational attraction as they passed too close to him, and swung them into shorter periods. The other great planets have similar "families," though composed of fewer members. In 1770, a bright comet was discovered having a period of only five or six years. This should, therefore, have been seen before, and many times since; and yet it was visible just that once. What happened almost certainly is this; coming from far outside the planetary boundaries upon its sunward journey, either returning in a great ellipse or passing in a parabola, it approached too close to Jupiter, who whirled it into a short-period orbit. Upon its first return in this new path the

Earth was so placed that the comet was not visible; and upon its passing outward it again went so near Jupiter that the latter threw it into an orbit so entirely different that it never has been seen since.

Up to the time of Edmund Halley in the 17th century, all comets were supposed to be visitors from far space. It was because of this, doubtless, that so much fear attached to their appearance. The great Newton showed in 1680 that the orbit of a comet then visible could be either a hyperbola, a parabola, or an ellipse. Halley, studying the comet of 1682, was struck by the similarity of its path with that of the comets of 1607 and 1531. After careful research and calculation, using Newton's figures of two years previous, he arrived at the conclusion that they were all one and the same comet; and he then predicted its return in 1758. This prediction was fulfilled, and Halley's modest plea, that if it should return, "impartial posterity will not refuse to acknowledge that it [the return] was discovered by an Englishman," was met by giving his name to this now most famous member of the cometary ranks. Halley's comet has since appeared in 1835 and 1910.

HALLEY'S COMET

Photographed May 13, 1910. Note the peculiar shape of the tail and the meteor trail crossing it. Length of tail 50°
The round spot of light is the planet Venus
From a photograph taken at the Lowell Observatory

The number of comets is legion. Hardly a year passes without the discovery of at least several small ones. The great ones, however, are scarce, about 20 to 40 per century, and only a small minority of these are well remembered. Some of them have been so bright that they have been visible in full daylight, an example of which was seen but a few years ago.

Some of the more famous of the comparatively recent comets are:

Comet of 1680. This was of marvellous size and brilliancy and inspired such terror that a medal was distributed in Europe to quiet apprehension. A free translation of the inscription upon this medal is: "The star threatens evil; trust only! God will make all right." It was this comet which inspired Newton to compute its possible orbit.

Comet of 1682. Halley's Comet. It is interesting particularly as the first one to have its return predicted. It is the appearance of this comet in 1066 which is depicted upon the famous Bayeux Tapestry. Its return in 1910 was not well viewed from the Northern Hemisphere and the casual observer here was, in consequence, disappointed. In South Africa and Australia the comet was a most beautiful sight.

Comet of 1772. Biela's Comet. A small comet but interesting as the first seen to disintegrate, as described above.

Comet of 1811. Another very beautiful and brilliant comet. Its orbit is calculated to extend over 40,000,000,000 of miles from the Sun. It will not return for over 1500 years.

Comet of 1843. One of the most brilliant of all comets. It was visible close to the Sun in full daylight. Much fear was caused in some quarters lest it presage the end of the world as predicted for that year, by William Miller, the religious fanatic, who, during the previous decade constantly reiterated this prophecy. This comet passed nearer to the Sun than any other body ever seen, and, as it rounded the Sun, moved at the terrific speed of over 300 miles per *second*. It has a period of about 500 years.

Comet of 1858. This is better known as Donati's Comet, named after its discoverer. It is the most beautiful on record, having a very brilliant star-like nucleus, and a series of wonderful curving tails. From it much valuable information as to cometary composition was obtained by means of the spectroscope, the value of which was then beginning to be appreciated. Its period is about 2000 years.

Comet of 1882. This was a splendid comet with a great tail shaped like a Turkish scimitar. It was of particular interest because of a peculiar multiple nucleus.

Comet of 1908. Moorehouse (discovered by). A small comet of great interest because of some amazingly rapid and great changes in its tail. This tail, in the course of a very few hours, was seemingly twisted and torn as if by external agency.

CHAPTER XIV

METEORS OR "SHOOTING STARS"

OCCASIONALLY, on a clear night, a long trail of light flashes for a moment across the sky. This is the well-known phenomenon of the "falling"—or "shooting-star." Sometimes, in a tremendous blaze and with a great rushing sound, often almost explosive, a mass of stone or metal hurls from the sky to the Earth, is found, and called a meteorite, an aërolite, a bolide, or half a dozen other technical names. They are really all one and the same thing—a meteor.

The meteors are particles of matter of various sizes and compositions, revolving through the Solar System in regular orbits, usually very elliptical. Most of them travel in swarms, and it is when the Earth meets such that we have the "shower of shooting stars." The orbits of most of these swarms are well-known.

The visibility of a meteor depends entirely upon its collision with the atmosphere of the

Earth at very high speed—up to 40 miles a second. This, by the great friction, generates a terrific heat, and the meteor (1) is either dissipated in fine dust, (which is often found on the Arctic ice) or, (2) if it be a large one, reaches the surface of the Earth as a much pitted and scarred mass of stone or metal, or, (3) only grazing the atmosphere, passes out before being entirely consumed.

The Earth is undergoing a constant meteoric bombardment, and were it not for our protective atmospheric shield, we undoubtedly should suffer greatly.

It is from the visibility of meteors that attempts have been made to gauge the height or depth of the atmosphere. It would seem to be dense enough at about 100 miles to cause the friction necessary to produce the white heat of meteors, at which height, as a rule, they become visible.

More meteors are seen in the early morning hours than in the evening because at the former time we are at the "bow" of the Earth, in relation to its orbital motion, and are in a position to see more "collisions" than in the evening, when we are at the "stern," and see only those meteors which collide in *overtaking* us.

In a meteoric shower if all the trails are traced back, it will be found that they all very closely approach crossing at a definite point in the sky, like the ribs of an open umbrella viewed from underneath. This is called the *radiant point* and is the direction from which the meteor swarm is coming. The meteors of swarms all move in parallel paths, and it is perspective alone which makes them appear to shoot in various directions. If one came from the radiant point directly toward the observer, it would appear as a sudden brilliant star *without motion*, simply growing more brilliant until it burned out, or fell to Earth at the observer's position.

The radiant point of a meteoric shower bears an apparent relative position to the "fixed" stars, and the swarms are known by a name connected with the constellation from which they appear to come: the Leonids, being apparently located in the constellation Leo; the Perseids in Perseus; the Andromedes in Andromeda, etc.

Observations of great meteor showers run back for hundreds of years, but it was not until comparatively recently (1833) that these showers were known to be periodic. In 1862 a remarkable connection was pointed out between the August meteors, the Perseids, and the comet of 1862. Soon, other instances of like association were discovered, and we now know of at least eight different meteor swarms connected with comets. It would seem that a comet is but a condensed section of a meteor swarm, or the meteor swarm a disintegrated comet. As an example of the latter, the case of Biela's comet and the subsequent meteoric shower is cited in the previous chapter.

In size, meteors range from tiny particles up to masses several tons in weight, the largest which has been found on the Earth weighing five and a half tons. This fell in Brazil in 1816. The small ones, of course, never reach the ground, and indeed the incandescence of the smallest certainly cannot produce light enough to make them visible.

The composition of such as have reached us for examination seems to place them in two main classes, those of stone and those of iron.

From the occluded, or absorbed, gases that may be extracted from them in a laboratory by heating, it is believed that they must have been at one time part of some vast body, later torn to pieces, as such gases could have been absorbed only under great heat and pressure. The irregular shape of meteorites also points to their being fragments of a whole, not small whole units in themselves. From these facts, much has been deduced about the origin of our whole Solar System from a great parent body, shattered by some tremendous collision in the ages past, meteors and comets being the unswept-up chips in the great workshop.

The better-known meteor swarms are: The Perseids of August, seen best as a rule on the 10th or 11th of the month. This is a broad stream, evenly scattered all around its orbit, for we meet them every year.

The Leonids of November, a compact swarm, which the Earth meets on November 14th in the early morning. There was a magnificent display of these in 1833, and again in 1866, their periodic time being 33 years. They were due again in 1899 but failed to appear, save as a very much inferior spectacle. It was later calculated that they had passed close to one of the great planets and their orbit in consequence had been

THE MILKY WAY ABOUT CHI CYGNI

A splendid example of a Star Cloud is shown at the center of the picture
From a photograph taken at the Lick Observatory

SOUTHERN REGION OF ORION

The lager light blur in the center of the photograph denotes the position of the great nebula

The bright streak is a meteor trail. Note the increase in brightness and the subsequent fading

From a photograph taken at the Yerkes Observatory

changed, so that the Earth no longer meets the thickest part of the swarm.

The Andromedes of November, a swarm seen on the 24th. This is the one connected with the disintegrated Biela's comet.

The Geminids seen about Dec. 7th.

The Orionids seen as a rule near Oct. 19th; and several others, the dates of which can be found in observers' handbooks.

All of these swarms are more or less scattered throughout their orbits, so that the Earth upon the date of crossing these orbits, always encounters a number of them. The *great clusters*, however, come only once in their periodic times of revolution about the Sun.

CHAPTER XV

ECLIPSES

THAT an eclipse of the Sun is caused by the Moon passing between it and the Earth, and that an eclipse of the Moon is caused by the latter entering the great shadow the Earth casts into space, is too well known to require any space here.

As explained before, the Moon's orbit around the Earth is inclined, or tilted, to the plane of the ecliptic, *i. e.*, the plane of the Earth's orbit around the Sun. It is only when the Moon is at, or near, one of the points where its orbit cuts the plane of the ecliptic, and, simultaneously, the Sun, also, is apparently at, or sufficiently close to, one of them that an eclipse can occur. It is for this reason that the plane of the Earth's orbit is call the ecliptic. In one year there may be as many as seven eclipses, five of the Sun and two of the Moon, or four of the Sun and three of the Moon; or as few as two eclipses but never less. When there are but two eclipses these both *must be* of the Sun. The Moon is never eclipsed more than three times in a year.

There is a certain time cycle, of about 19 years, called the *Saros*, at the end of which begins a repetition of eclipses similar to those of the previous 19 years. This Saros was known to the Chaldeans. It is not exact, but is close enough to be of practical value.

The reasons for the above are all technical and mathematical, and, as such, have no place here.

Eclipses of the Sun are more numerous than those of the Moon in a ratio of about three to two, but, from any given point on the Earth more eclipses of the Moon may be seen than those of the Sun. A solar eclipse, because of the small width of the Moon's shadow, can be seen from only a limited position of the Earth, but an eclipse of the Moon can be seen from a whole hemisphere at the same time.

Eclipses may be roughly divided into two main classes, total and partial.

ECLIPSES OF THE SUN

A total eclipse of the Sun is visible from some point on the Earth about once every year and a half. At any given place, however, one is seen only about once every 360 years. This is because of the narrowness of the Moon's shadow, this averaging only about sixty to seventy miles in width.

An eclipse is called *total* when the Moon's disk entirely covers that of the Sun. Because of the varying distances of the Moon from the Earth, and the Earth, and consequently the Moon, too, from the Sun, the apparent sizes of the Moon and the Sun vary. There are, therefore, eclipses where the solar disk is barely covered, and others where it is completely screened. The *total* stage of solar eclipse can last, at most, only about eight minutes. The shadow of the Moon travels at the Earth's surface with the speed of a cannon ball, and only under the best conditions can an eight-minute totality occur. This can happen only at the Equator, and at the very center of the path of 168 miles in width made by the Moon's shadow when broadest.

It is only during the total stage that the wonderful Solar Corona is seen. Whenever a total eclipse occurs it may be seen also as a *partial* eclipse on a strip of the Earth's surface several hundred miles on either side of the path of totality.

An eclipse of the Sun where the disk is not covered *entirely* although the Moon is passing *directly* between the observer and the Sun, or centrally as it is termed, is called an *annular* eclipse because of the ring (Latin, *annulus*) of the Sun's rim left shining around the black disk of the Moon. An annular eclipse occurs when the Moon is farthest from the Earth, and the Earth and Moon are nearest the Sun, and in consequence, the shadow of the Moon is not long enough to reach the Earth. The annular eclipse is, of course, only a special form of partial eclipse.

The third form of the solar eclipse is the *partial* type. This occurs when the Moon passes over the Sun's disk not centrally. It may range from an almost total eclipse to a bare shading of the Sun's rim.

The total eclipses are those of greatest astronomical interest.

ECLIPSES OF THE MOON

These are either total or partial. A total eclipse of the Moon occurs when it passes entirely into the shadow of the Earth. The diameter of the Earth's shadow where the Moon crosses it is about 5700 miles. The Moon, therefore, with a diameter of 2162 miles can be quite "out of line" and still be totally eclipsed. When the Moon crosses the center of the shadow the total phase lasts about two hours. The duration of a non-central eclipse varies according to what part of the shadow is traversed.

Owing to the refractive power of the Earth's atmosphere, the rays of the Sun are somewhat bent around the Earth, so that its shadow is never clearly defined, as is that of the Moon; and, even when the latter is totally immersed in the Earth's shadow, its disk is usually visible, glowing with a dull, copper-colored light. The color is caused by the passage of the Sun's rays through such an extent of our atmosphere. From the Moon, during a total lunar eclipse, the Earth must appear as a great black disk surrounded by a narrow ring of brilliant light, colored with sunset tints. In 1884, the cloudy condition of the Earth's atmosphere prevented the passage of practically all this refracted light, and the Moon for a time was quite invisible to the naked eye. This was a most unusual occurrence.

A partial eclipse of the Moon occurs when the edge of the Earth's shadow only is traversed. Like a partial eclipse of the Sun, it may range from the barest touching of the Moon's edge up to an almost total phase.

Eclipses were probably among the very first celestial phenomena to be studied. We have records of them dating back several thousand years.

The value of a total solar eclipse lies in the opportunity it gives for studying the wonderful Corona about which so very little is known. Expeditions are nearly always sent out from every large observatory to that part of the world from which a predicted total solar eclipse will best be observed. During the totality, but little attention is, nowadays, paid to direct observing, all efforts being centered upon obtaining as many good photographs of the phenomenon as possible. Direct observations can last only during the eclipse, while photographs may be effectively studied for years, and form a permanent record of that eclipse. Dry, high countries are of course, the most suitable for the placing of such eclipse stations, since a few moments of cloud at the wrong time will prevent all observation, and render entirely useless a costly and laborious expedition. Unfortunately, it is not always possible to find a good station in the path of the eclipse, and, in consequence, many an expedition has gone for naught.

Until the spectroscope proved its ability to view them under ordinary conditions, the study of the Solar Prominences was also restricted to the scant few moments of totality during an eclipse.

Lunar eclipses present to the scientist no features of special interest.

The ability to reckon backward for centuries eclipses of both the Sun and the Moon has helped greatly in establishing historical dates of events occurring near eclipses mentioned in old records.

CHAPTER XVI

THE FIXED STARS

JUST as our Sun is a star, so the stars are suns, great flaming masses of gases at enormous temperatures, brilliant with a light of their own, and so huge that they may continue to give light and heat for millions of years before they cool. "What has been said of the Sun probably applies in a greater or less degree to the great majority of the stars," but so vast is the distance which separates even the nearest one from us that, despite their enormous volume, they appear only as mere points of light. It is safe to say, however, that the majority of them are larger and hotter than the Sun and like the latter rotate. It is probable, this from analogy only, that a great many of them also have their family of planets.

The composition of the stars as well as their physical condition varies. The spectroscope reaches across the great void of space, and, to a large extent, analyzes these bodies for us. We find that many well-known substances, such as iron, hydrogen, calcium, etc., seem to be universally distributed throughout the stars, but we also find that variety in composition is not unusual. Some stars show, under spectroscopic analysis, substances which we do not know on Earth, and again seem to lack substances which are main factors in the make-up of other stars. Indeed, the stars have been to a certain extent classified according to their composition. It is interesting to note, in connection with the unknown elements of the universe, that helium was found in the Sun, hence its name, long before it was discovered upon the Earth. It is quite possible therefore that chemistry will reduce the element or elements causing the enigmatical lines in the spectrum of the "Orion type" stars, a class which seems to stand quite alone.

It seems probable that most of the stars are much less dense than the Sun; in many cases it is possible to measure stellar density with a certain amount of accuracy and in all such instances these densities are "far less than any of our solid or liquid substances; frequently no greater than that of air, sometimes even less."

It is also probable that most of the stars are vastly larger, and are thousands of times more luminous, than the Sun. A star such as Canopus, visible from southern latitudes only, is known to be *over* 2500 trillions of miles distant, and quite possibly much farther away, and yet it shines with a brilliancy surpassed by only one of the nearest stars.

The stars are called "fixed stars" because of their apparent permanent relative positions, in contradistinction to the planets, the wanderers, which, to the naked eye, look like stars, but can be seen to shift their positions from night to night.

From any point on the Earth, the heavens appear as a great dome, or one half of a vast sphere, with the observer directly beneath the highest point of the arch. Were it possible to remove the Earth, and leave the observer suspended in space, it would be seen that the sphere was complete, with the observer's position exactly at the center. This sphere seems to be studded with the stars, all of them appearing as equally distant. This, of course is but an optical illusion. The Moon seems equidistant with the stars, as do also the planets, and yet

Jupiter is many millions of miles away, the Moon but half as many thousands, and even the nearest of the stars many million millions. The astronomers, however, make good use of this illusion and treat this apparent sphere as if it were an existing concrete object. Upon it the positions of the heavenly bodies are marked by a system exactly corresponding to the geographic method of defining the positions of a place by stating its latitude and longitude.

We do not see the stars in the daytime because of the diffusion through our atmosphere of the brilliant light of the Sun. Were our atmosphere removed, the stars would be always readily visible at even high noon. Even now, under the present conditions, it is possible to see some of the brighter stars in the daytime if the observer be stationed at the bottom of a sufficiently deep shaft, thus cutting off the larger part of the daylight.

This Celestial Sphere, as it is called, appears to revolve constantly about the Earth from east to west, making one revolution in a day. As we know now, this motion is only apparent, and is caused by the rotation of the Earth in the opposite direction. For this reason, the axis of the Celestial Sphere is merely the axis of the Earth prolonged; its Poles, the points where the Earth's axis cuts its surface; and its Equator similar to that of the Earth, a line encircling it equidistant from these poles.

The present north pole of the Celestial Sphere is close to a bright star, which is called in consequence Polaris, or the North Star, but, owing to one of the Earth's motions, a "wobble" on its axis like a huge top, this pole is not a constant point. In the course of about 26,000 years the Earth's axis describes a circle on the Celestial Sphere, so that 13,000 years from now Polaris will be far from being the North Star, which honor will be held by the bright star Vega of the Lyre. But, 13,000 years later, Polaris once again will be in its present relative position to the North. Some 4000 years ago Thuban of the Dragon was the North Star, and, it is said, it was for the purpose of viewing this star at all times that the great slanting tunnel in the Pyramid of Cheops was built.

The stars are not evenly divided about the Celestial Sphere. There is surrounding it a great encircling band of light, called the Milky Way, or Galaxy, which, under telescopic observation, resolves into thousands upon thousands of stars, so apparently close together as to shine not individually but as an almost solid belt of light. This is more fully described in the next chapter. In and near this Galactic belt is where most of the stars seem gathered, while at the points of the heavens most distant from this ring (the Galactic Poles) the stars are comparatively few and far between. It is this appearance which led to a theory that the Universe is in the shape of a great disk with the Solar System about at the center, so that looking "edgewise" or through its broad dimensions there are far more stars to see than when looking flatwise, or through the thin dimension. The theory that the Galaxy is an *actual belt* surrounding the sphere, is the more generally accepted of the two. However, this, at present, can be really only a matter of conjecture. Of the shape or extent of the Universe we have no definite knowledge.

Aside from the distribution of the stars just spoken of, the apparent grouping of them into "constellations" has been noticed from the most ancient times, and names given to such

LARGER STARS OF THE PLEIADES

Exposure too short to photograph nebulosity shown in frontispiece. Note the apparent distortion of largest star. This shows as four stars in even a small telescope

From a photograph taken at the Yerkes Observatory

groups. The names which are now used come to us from the time of Ptolemy in the second century, and are, for the most part, those of the mythological Greek heroes and their fellows, whose forms the ancients saw translated to the skies. These constellations are merely apparent. Two stars seemingly side by side may be actually billions of miles apart, one behind the other, so to speak, from the direction we view them. The stars forming the constellations have now been lettered and numbered, and are referred to as Alpha Canis Majoris, A of the Great Dog; Omicron Ceti, o of the Whale, etc. Many of the brighter stars also have individual names, the above two being Sirius and Mira, respectively.

Most of the constellations bear little resemblance to the fancied figures assigned to them by the ancients, but habit is strong, and, probably for many years, they will bear their present names. It is not possible to describe these groupings properly without devoting more space than is available here, and without assisting charts. There are several books listed in the bibliography written and illustrated with the proper maps for just this purpose.

The number of the stars is not known with any approach to exactness. It is certainly very great. Estimates have been given up to well over 100,000,000.

The number visible to the naked eye is about 6000. Only about one half of these, of course, are above the horizon of a place at any one time, and, owing to the absorption of light by our atmosphere, those close to the horizon are not visible. That our air does absorb light is demonstrated by the ease with which one may gaze at the Sun just as it is setting, while its noonday brilliance is unbearable. At one time and place therefore, even under the most perfect conditions, only about 2000 stars may be seen without telescopic aid.

With every increase in the size of telescopes more stars appear, and the photographic plate with its power of retaining the cumulative effects of light during a long exposure show stars which it is improbable will ever be *seen* with any telescopes constructed like the present ones.

The stars are apparently different in size and brilliancy and this has led to their classifications by *magnitudes*. The magnitude of a star tells nothing about its actual size, but only of its brilliancy as seen from the Earth. A comparatively small star in some cases far outshines one which we know must be of stupendous dimensions, but which is much farther away.

There are about 20 stars of the first magnitude, 60 of the second magnitude, 130 of the third magnitude, each star of one magnitude being somewhat between two and two and one half times more brilliant than one of a magnitude lower. The photographic plate has recorded stars of the 20th magnitude, giving *to us* thousands of times less light than the first magnitude stars. These magnitudes merge into each other on a decimal scale, and a star may be of magnitudes 9.2 or 3.4 etc.

The distances of the stars are almost inconceivable. Beyond the limits of the Solar System, whose dimensions we have seen are in themselves huge, stretches empty space for many million times a million miles. Our unit of a mile is useless for such vast measurements, and even the distance of the Earth from the Sun, the "yardstick" which is the standard for the Solar System, is too small. Astronomers have been forced to find a unit far greater than this: namely, the "light-year," which is the distance *covered by light traveling for a year* at the amazing speed of 186,000 miles per second. The light-year is equivalent, therefore, to 5,873,-286,000,000 miles. Some of the stars in the Milky Way must be thousands of these light-years distant.

The nearest star neighbor to our Sun is the third brightest star of the heavens, Alpha of the Centaur, a southern constellation, and its distance is 4.3 light-years, about 25 trillions of miles; the next nearest is a small *telescopic* star in the northern heavens bearing no name but merely a catalogue number, which is 8.1 light-years distant. Sirius, the Dog Star, the most brilliant of the heavenly host, is 8.7 light-years away. These distances are all known with fair accuracy.

But a very few of the stars are near enough to be measured, about one hundred only out of the many millions. In some cases it has not been possible to ascertain the real distance of the star, but it has been demonstrated certainly that the star can not be nearer than a definite limit. This applies to several of the *bright* stars such as Canopus, previously cited; Rigel, the gem of Orion; Deneb, A of the Swan; and Spica, A of the Virgin, which all *must be* over 500 light-years away. Their vast size and great light-giving power may therefore be imagined, when from such distances they can not only rival in brilliancy but actually outshine stars hundreds of light-years *nearer*, which latter nevertheless are known to be far greater than our Sun.

As was said, the distances of some of the stars in the Milky Way are placed at thousands of light-years.

One of the effects of the great star distances is that we do not see the heavens as they are, but *as they were*. The light which is just reaching us from the nearest star started about four years and four months ago, so that we are now seeing that star where, and as it was when the light left it. Were some distant star suddenly extinguished to-day, we should continue to see it shine night after night for even hundreds of years.

Not even the most casual observer of the stars can fail long to note the variance in color between many of them. Some, such as Vega of the Lyre, glitter with the blue-white of a first-water diamond; others, like Arcturus of the Herdsman, shine with a deep yellow light; and still others, like Antares of the Scorpion, Aldebaran of the Bull, and Betelgeuse of Orion, glow red against the sky. Many telescopic stars have even more pronounced colors, some hanging like drops of blood in the heavens and others glittering like wonderful sapphires.

These colors arise from different physical conditions of the stars, and, to a certain extent, from their composition. According to the accepted theory at present, the stars of the brilliant blue-white are the younger, while those of the deep yellow and reddish colors are the older, the red stage showing the greater stellar age. Our Sun is a yellowish star and is supposedly showing signs of advancing years.

Far from being fixed, it is known that all the stars are in motion; again it is only their vast distances which deceive us. A very moderate stellar rate is ten to fifteen miles *per second*, 864,000 to 1,000,000 miles per day, and yet it requires the most careful and minute measurements to show any change in a star's position even after many years. Despite this rushing helter-skelter at these speeds and vastly greater ones, the stars have displaced themselves so little that, did any of the ancient Grecian astronomers view the heavens to-day, he would find the constellations wheeling through the night almost as he left them twenty-five hundred years ago. Eventually, however, the aspect of the heavens will change and the constellations lose all resemblance to their present forms.

The most remarkable body, from the point of speed, is a telescopic star known only by a catalogue number, Groombridge 1830. This is hurtling through space at the terrific speed of over 200 miles *per second*. It is called the "runaway star," and no explanation for its speed is yet at hand. The mighty Arcturus, at least 100 times our Sun in volume, is rushing along at the speed of nearly 90 miles per second; 61 of Cygnus, interesting as the first star whose distance was satisfactorily measured, speeds at 50 miles per second, and many are known to have velocities of from twenty to one hundred miles per second. It is possibly safe to say that an average star speed is about fourteen to twenty miles per second.

Besides the motions of the stars across our line of sight, which results in changes of their positions on the Celestial Sphere, they have *radial velocity*, motion toward or away from us, directly in our line of sight. These motions are measured by the spectroscope, which shows us the speed at which a star is approaching the Earth. When the proper corrections are made for the motion of the Sun, which as has been stated is rushing along with the planets at a rate of about twelve miles a second, and for the motions of the Earth, as it revolves about the Sun, it is possible to give with a really marvelous accuracy the star's radial velocity. It is by reckoning, from the displacement of the star on the celestial sphere, its radial velocity and its distance from us, that the true motion of the star in space is calculated.

There have been attempts to show that the stars were moving in great orbits about some Central Sun, and for a time it was claimed that this central body was the brightest star of the Pleiades group. This now has been absolutely disproved, and no trace of such orbital motions has been found. There has been shown, however, a great star drift or rather two drifts, as if two universes had met and were passing through one another. These drifts are now being studied most carefully.

Many people ask why a star "twinkles." This is entirely caused by the refraction and disturbances in the Earth's atmosphere. Were this removed, the stars would blaze steadily in a deep black sky with a glory never to be seen from the Earth's surface. The planets do not twinkle, as the beams of light coming from them are comparatively "thick" and sturdy, while such are the distances of the stars that but the tiniest thread of their light reaches us; so tiny is this that the slightest disturbance of the air causes enough refraction to make the light flicker. A planet close to the horizon, when its light must penetrate more and denser air, most of which is in a greatly disturbed condition, will be seen to "flicker" as does a star. Mercury indeed, which is never seen far above the horizon, is, as previously stated, sometimes called the "Twinkler."

CHAPTER XVII

NEBULÆ

In the star-catalogs of the early writers we find mentioned a class of "nebulous or cloudy stars." The telescope proved that the very great majority of these are merely clusters of stars so apparently close together that they shine, except under fairly high magnification, as a blur of misty light. With the improvement of the telescope, however, many other "patches of light" were found, some of which could be resolved into separate stars, while others could not. The former of these were called *star-clusters*, and the latter *nebulæ*.

There are many thousands of these nebulæ; but only about ten thousand of them have been cataloged, and only two are visible to the naked eye, the great nebula in Andromeda, and the great Orion nebula.

For many years, the nebulæ were considered as anomalies in the cosmic system. Now, however, they are believed to be a regular and usual step in stellar evolution. It is considered that they are stellar systems in embryo. Their distribution in space would seem to support this, being quite the opposite of star distribution. That is, where the stars are the most numerous, in the Milky Way and the neighboring regions, the nebulæ are scarce; and, conversely, at the poles of the Galaxy, where the stars are few and far between, the nebulæ are to be found in the greatest numbers. There seems nothing improbable, therefore, in the theories that, in the Galaxy, the stars have, so to speak, consumed in their formation the material of which the nebulæ consist; or, on the other hand, as some astronomers have suggested, the nebulæ have been formed by the *disintegration of stars*. The former theory seems to be more generally accepted, but whichever view is correct, the nebulæ are certainly a regular part, at one extreme or the other, of stellar evolution. It is quite possible that both views are right, and that from the disintegration of one system springs a new one.

In considering the evolution of stars from nebulæ, or *vice versa*, it is well to remember that in many cases the two types are unquestionably in close connection. The well-known group, the Pleiades, is suffused throughout by a faint nebulous light (*see* frontispiece), and each of its stars is enveloped in a dense fog of light-mist, to such an extent that there can be no doubt as to either the origin of the stars from a great nebula, or the beginning of a nebula from the emanations of the stars.

There are, also, isolated *nebulous stars* to support the evidence which points to an intimate relation between these two apparently different forms of matter. "There is a vast difference between a nebulous star, and a star in a nebula" (Swift). For, while a star in a nebula may only appear to be there, as a result of perspective, the luminous halo surrounding a nebulous star cannot be disassociated from the star itself. A nebulous star has, as a rule, the appearance of a rather bright point of light at the center of an aureole of faint luminosity which fades off into the darkness of space in an almost perfect gradation.

Practically all nebulous stars show, under the analysis of the spectroscope, characteristics which are associated with "youthful" stars, and this also would seem to lend support to the theory that stars are actually formed from condensations in nebulæ, and that a nebulous star is one taking the early steps along its path of evolution.

Nebulæ may be classified, in regard to shape, as: Spiral; Ring, or Annular; Planetary; and Irregular.

The SPIRAL form of nebula is by far the most common. It is to this class that the great Andromeda nebula belongs. One of the best examples of this shape and class, the "Whirlpool" nebula in the constellation Canes Venatici, is shown in the accompanying illustration. The resemblance to a fireworks "pin-wheel" is very striking, and it is, indeed, most probable that just such a rapid whirling motion is there present. That we cannot see, and have as yet been unable to measure, any consequent change in form or position, is due both to the immense sizes of the nebulæ, and to the almost inconceivable distances which stretch between them and the Earth. Each of these spiral nebulæ shows a marked large central condensation, while along the curved arms that whirl from this centre are beaded smaller knots and thickenings, so that it is very easy to deduce their ultimate condition as that of a vast system, where perhaps many hundreds of smaller stars, which, of course, may cool into planets, swing in great orbits about a huge central sun.

The RING, or ANNULAR, NEBULÆ may easily be but a somewhat unusual form of the spiral,—a "drawn-out" spiral like a spring, which, when viewed from "on top" appears simply as a ring. One of the best known ring nebulæ has recently been proved to be of this helical shape. The ring nebulæ are always darker at the centers than at the borders. The most famous one, in the constellation Lyra, appears in a large telescope as a well marked ring of light surrounding a dark central space, in the middle of which, or *through the middle of which*, from possibly far beyond, shines a small star.

The PLANETARY NEBULÆ were so named by the elder Herschel, because of their appearance. They are small (comparatively speaking), circular or elliptical nebulæ, which through a telescope present an almost evenly illuminated disk, somewhat like that of a planet. Nearly all of them may be recognized by a characteristic greenish tinge.

NEBULA (N.G.C. 6992) IN CYGNUS

A wonderful example of an irregular nebula. Note the very faint lace-like appearance
From a photograph taken at the Yerkes Observatory

THE "WHIRLPOOL" NEBULA IN CANES VENATICI

One of the most evident spiral nebulæ. Note the striking resemblance to a "pin-wheel," also the beading of the curving arms
From a photograph taken at the Lick Observatory

The IRREGULAR NEBULÆ are of almost any shape. The great nebula of Orion, shown in the illustration, facing page 136 is the most famous of this class. Some of these are but the faintest, misty wisps of cloudy light, detected only by the photographic plate, while others are comparatively bright, and are easily observed in even a small telescope. A number of the irregular nebulæ have special and distinctive names, such as: The Dumb-bell Nebula, The Crab Nebula, The North America Nebula, The Owl Nebula. These names have been given to them because of a very real, not a fancied, resemblance to their namesakes.

The real constitution of nebulæ is yet largely a matter of speculation. The spectroscope divides them into two classes, the *white* and the *green*.

The white nebulæ, to which class the spirals belong, and which are in consequence by far the more numerous, show, under the spectroscope, that they probably are composed of solid particles; but, as gases under pressure would give a similar spectrum, this is not yet certain. There is such difficulty in collecting enough light from a nebula to obtain a good spectrum of it, that great advances in the quality of our instruments must be made before a definite knowledge of this sort can be acquired.

It is known definitely, however, that the irregular and the planetary nebulæ, as well as other subdivisions of the green nebulæ which have not been mentioned, are of a gaseous composition. Their spectra are too evident to allow uncertainty. These gaseous nebulæ, the planetary in particular, contain a substance yet to be found on the Earth. This has a characteristic marking in the spectrum and is easily recognized. It has been given the name "nebulium."

It has been shown that all nebulæ must be of extreme rarity, far beyond that obtainable by artificial means. Stars shine in and through them with no appreciable diminution of light. Granting the truth of the *lowest* estimate for the distance of the Andromeda nebula, its gravitational pull on the Earth would be as great as that of the Sun had it a density equal to $\frac{1}{300,000,000}$ that of our "day-star." As we can find in the Solar System no disturbing effect which can be attributed to such an exterior gravitational pull, it is evident that this particular nebula, at least, must be of a density approaching "nothing at all."

The sizes of most of the nebulæ are probably vast beyond belief. It has been demonstrated, with an approach to certainty, that the great Andromeda nebula cannot be less than *eight light-years in diameter*—that is, it would stretch from our Sun into space for a distance nearly twice as great as that which intervenes between us and the nearest star, and yet this star, huge as it is, shines to us as only the tiniest *point* of light.

All the nebulæ lie at tremendous distances. Most of them are beyond the limits of measurement; this again points to the enormous areas covered by them.

The nebulæ seem to be in motion like all other bodies in the universe. Their proper motions have not been measured, but the spectroscope reads their radial velocities, their motions to and from us.

It is not at all impossible that there exist many *dark nebulæ*, of the same general nature as those shining with a light of their own, but flying unnoticed through space. In fact, the dark nebula has been called upon to explain several of the unsolved problems of the universe, such as the temporary star and the "coal-sacks" in the Milky Way. As, however, we can study only the visible members of the stellar horde and a few of the dark members by their effect upon their visible fellows, the non-lucent nebula must remain, for the present at least, merely speculation, however probable a one.

Just what makes a nebula luminous is also unknown. It is impossible for matter in such a rarefied form to be what we call *hot*, so that they cannot be incandescent, as is possible, and probable, with the stars. Electrical energy is the most plausible explanation, this producing the luminous effect somewhat as in the vacuum tube in a laboratory.

It has been the photographic plate which has enabled us to study best these "ghosts of matter." Most of them are very disappointing sights in even the great telescopes, but the camera, with its ability to retain the cumulative effect of light, brings out a wonderful wealth of detail far beyond the eye's power to grasp.

A theory has been advanced that, in case of

THE GREAT NEBULA IN ORION

The best known example of the gaseous nebula
From a photograph taken at the Yerkes Observatory

the Andromeda nebula particularly, we are seeing beyond our own universe, and viewing another great and similar system far out in space. While this would account for the "continuous spectrum" showing the probability of the nebula being composed of solids (and, therefore, says the originator of the theory, why not actual stars too far away to be seen separately), other and recent measurements and observations do not support this splendid effort of imagination.

CHAPTER XVIII

FREAKS AND ODDITIES OF THE SKIES

THERE are many curiosities in the skies to which individual space must be devoted. These may be divided into Star Groupings (other than the constellations), and the Abnormal Stars, some of the last being true freaks indeed.

STAR GROUPINGS

These may be classified as: The Milky Way or Galaxy, spoken of in the last chapter, the *great* grouping; and the small ones, the Star Clouds, Star Swarms, Star Clusters, and Star Streams. There must also be mentioned those strange "holes" in the universe known as the "Coal-Sacks."

THE MILKY WAY. As described before, this seems to be—and a certainty in the matter is being approached—a vast actual ring of stars encircling the whole of the visible universe: "a ground plan of the system." To the casual observer it appears only as a hazy band of light, brighter in some places than in others; but a little closer observation will show that the ring is irregular, and not homogeneous. It is broad and diffuse on one side, and narrow and well defined on the other. Also, it is split in two by a great rift for about a third of its circumference. More careful looking will show that it is marvelously complex in detail. The telescope only can show its true beauty and wonder. Viewed with the aid of even a small instrument, the Galaxy is seen to be composed of millions upon millions of stars unevenly distributed along it in knots, clusters, streams, and clouds, and in some places with the effect of almost moving swirls of light. It has been estimated that the Galaxy contains about thirty stars for every one existing outside its borders.

Many of the first-magnitude stars seem associated with this great "ground plan of the Universe," and some of the bright groups of stars, such as the Pleiades and the Hyades, in the constellation Taurus, appear to be hung from it like pendants from a necklace, suspended by faint loops from the main ring.

STAR CLOUDS are found almost without exception in the Milky Way. These were first photographed by Professor Barnard, and not till then was their true beauty known. The resemblance to the clouds of our atmosphere is so close as to be startling, every variety of formation being clearly portrayed. It must not be supposed, however, that, despite the appearance, the stars of these clouds are literally crowded together; this is only the effect of the perspective of thousands of light-years. It is unquestioned, nevertheless, that they are much nearer to each other than the Sun and its neighbors, and the night sky, viewed from a planet whose sun formed a member of such a cloud, would be of a glory almost inconceivable.

There are two great exceptions to the rule that Star Clouds are not found beyond the limits of the Galaxy. These are the "Magellanic Clouds," two "patches of hazy light," looking like pieces fallen from the great ring, and of essentially the same structure as the latter, so much so that it is only their separation from it which makes them of especial interest. They may be seen only from southern latitudes.

Star Swarms are also characteristic features of the Milky Way. They are merely coarse Star Clouds; in other words, their component stars, while very numerous, retain to a certain extent, their individuality, and do not merge together in a misty light as in a Star Cloud. This may be either because they are nearer to us, or because the stars are larger or more brilliant than those composing the Star Clouds, or for both reasons.

Some of these can be seen with the naked eye, the most conspicuous example being the "double-cluster," as it is called, in constellation Perseus. This glows only as a tiny patch of light to the eye unaided, but viewed through a telescope it is a marvelous sight. The illustration facing page 144 is from an excellent photograph. The reasons for these groupings into Star Swarms and Star Clouds is not known, nor has any tenable theory been advanced.

Star Clusters are smaller than the groupings just mentioned, and the term is properly applied only to those which show a globular shape, by far the most characteristic appearance. They are more numerous in the Milky Way than outside its boundaries, but many are found with no association to the great ring. The most notable example in the northern hemisphere is the great cluster in the constellation Hercules. This is visible to the naked eye as a faint glow of light. A small glass will show its character; but the astounding *live* beauty of it is apparent only with the aid of a large telescope. A photograph cannot show the wonders of a cluster for the stars at the center are lost in an indistinguishable blur (see illustration facing page 160). In fact, this effect is seen to a lesser extent even when viewing the group through a telescope.

Herschel estimated that the Hercules cluster contains about fourteen thousand suns, each, however, probably much smaller than our Sun; five thousand is probably more nearly correct. Marvelous as the sight is to us, how much more beautiful to an inhabitant of a near world!

Here, as with the Star Clouds, the perspective deceives us. The stars are not packed closely, but are probably separated by millions of miles. However, the globular shape of the clusters, and the arrangement in more or less curving and radiating lines of the dispersed stars surrounding the cluster proper, have led to the suggestion that the whole is the ***result of an explosion*** of a vast sun. The well supported observation by Herschel, that space near these clusters is unusually vacant, as in the region of the nebulæ, seems to point to a less spectacular origin, namely a gradual drawing together of the neighboring stars towards the central condensation of a nebula.

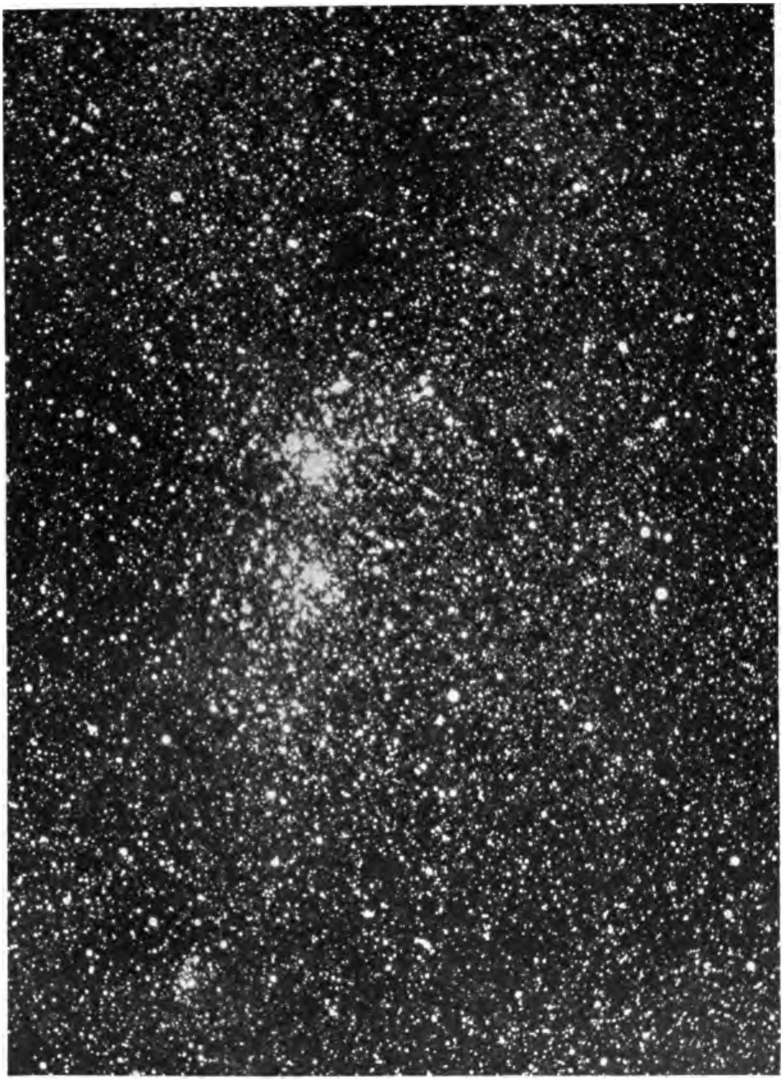
There is a still greater globular cluster in the southern hemisphere, in the Centaur, which constellation also contains the Sun's nearest neighbor. This is a replica of the Hercules cluster in all respects except size.

STAR STREAMS are simply "drawn out" star swarms or clusters. The Galaxy is replete with them, but no true examples are found outside its limits.

The "Coal Sacks" is the inadequate name given to the inexplicable dark, starless gaps that appear here and there in the radiance of the Milky Way. The first noticed, and best known, is close to the "Southern Cross." For years, and in fact at the present date, this is regarded with a superstitious awe by many, particularly the sailors, those accustomed watchers of the skies.

Up to the very edge of this dark hole the Milky Way is extremely bright, and then is extinguished abruptly. One faint star shines within the opening, making the surrounding blackness the more profound by contrast. The shape of the "Sack" is that of a pear, and the dimensions about eight degrees by five, giving an area of over 125 times that of the full Moon. Photography has shown that the southern part of this is not as vacant as it seems, but the northern part is, apparently, bottomless beyond imagination.

There is another well-known "Coal Sack" in the northern hemisphere, in the constellation Cygnus, and, curiously enough, adjacent to the part of that constellation called the "Northern Cross." This is neither so large nor so well marked as the other, but has rather the appearance of a veil drawn over the stars, lending support to the theory that in this direction we are looking *through* a dark nebula.



THE DOUBLE STAR SWARM IN PERSEUS

This is visible to the naked eye, and evident in a small glass, but a good telescope is needed to bring out its great beauty

From a photograph taken at the Yerkes Observatory

In the constellations Scorpio and Sagittarius are a number of small "Coal Sacks," none, however, comparable in size with the two large ones mentioned.

Again, many theories have been advanced to explain these strange "windows of absolute night," as Serviss calls them, but it seems certain that, though some of them may be the result of the interposition of dark nebulæ, the majority are actually holes in the boundaries of our universe through which we gaze beyond into, as far as man can know, infinite space.

ABNORMAL STARS

There are in the skies many stars apparently quite different from the normal "every-day" variety as seen by the naked eye.

These may be divided into the following classes: Double and Multiple Stars, Binary Stars, Variable Stars, and New or Temporary Stars.

Double Stars. There are many stars seemingly single points of light to the naked eye which, with the aid of the telescope, may be resolved into two or more stars. In some cases this is merely the result of perspective. Two stars nearly in a line when viewed from the Earth, will, although billions of miles apart, one farther away from us than the other, appear side by side on the apparent celestial sphere. In many cases, however, the stars are actually close together.

Many of these double stars show beautiful contrasts in color. The star Beta of Cygnus, for example, can be separated into two by even a small glass, the primary a brilliant topaz, and the smaller star a wonderful peacock blue, while Gamma of Andromeda separates into an orange-colored primary and a smaller star that shines like an emerald. This color contrast in double stars is the rule rather than the exception, but some of the famous doubles are of the same shade. Castor of the Twins divides into two blue white diamonds of almost equal brilliancy, and Mizar, the star at the bend of the handle of the "Big Dipper," and little 61 of Cygnus, the star whose distance was first measured, both separate into pairs of nearly the same color.

Multiple Stars are not nearly so numerous as simple doubles. There are many known, however. The sextuple star in the heart of the

Orion nebula is the best example. A small telescope shows this as four stars only, placed in the form of a trapezium, but a large instrument adds two more to the group.

The small naked-eye star Epsilon of Lyra is just separable by a good eye. A telescope again divides each component, showing a system of four stars. The observation of Double Stars is one of the pleasures within the grasp of the owner of even a small instrument.

Binary Stars are merely double stars whose orbital revolution about each other has been proven. They are, as a rule, much closer together than the average "double." Castor, mentioned above, is a fine example of a binary system.

Many stars that defy separation with a telescope yield their secret to the spectroscope and are proven close doubles. These, in consequence, are called spectroscopic binaries. Each component of the telescopic double Mizar of the Great Bear, also mentioned above, has been proved to be a double, though no telescope will ever be able to show the four stars.

A VARIABLE STAR, or merely a variable, as it is more commonly known, is one whose magnitude—that is its brilliancy as viewed from the Earth—changes from time to time, these changes being in some cases slight and in others very great, and occurring usually in a comparatively regular cycle.

The variables are generally classified as "short period," those whose cycle is completed in a few days or less, and "long-period," those which require more time, in some cases even years.

The SHORT-PERIOD VARIABLES may be subdivided into those whose variation is caused by a partial eclipse of the brilliant star by a companion star, a close binary, the two revolving about each other, and those where the variation is partially due to some real change in the star itself which alternately blazes up and smolders.

The best known example of the former class is the star called "Algol," which shines in the constellation Perseus. With great regularity, every two days twenty hours and forty-eight minutes, the light of Algol undergoes a rapid change, first decreasing over a magnitude, and then regaining its full brilliancy, the duration of the whole phase being nine hours and twenty minutes. This means that at maximum the star gives over twice as much light as it does at minimum. This peculiar behavior of Algol has been long known, and its name, signifying "The Demon," shows the riddle it propounded. By the aid of the spectroscope this riddle was solved, and it is now known definitely that Algol is a system of two stars, one bright, the other comparatively dark, and invisible even with the aid of the great telescopes. These revolve about each other—that is, around their common center of gravity, as do the Earth and Moon—in a period exactly equaling the cycle of Algol's variation in magnitude. It is the passage of the dark star between us and Algol which, by partially eclipsing the latter, cuts off from us much of its light. From spectroscopic observations of the movements of the bright star in its orbit, it is possible to estimate, with a fair approach to certainty and accuracy, that Algol is about 1,000,000 miles in diameter, its dark companion about 765,000 miles in diameter, or slightly larger and slightly smaller, respectively, than our own Sun; and that the bodies are about 2,250,000 miles apart from surface to surface.

Constant observation has, in the past few years, added many variables to this "Algol type," some of which are almost faultless timekeepers.

Another well-known variable of short period is the star Beta of the constellation Lyra. Unlike that of Algol, the light change in this case is not a simple rise and decline. The brilliancy rises to a maximum, declines about *halfway* to minimum, *rises again to maximum*, and then sinks back to full minimum, the total cycle requiring about thirteen days. The variability of this star is supposed to be caused almost entirely by the mutual eclipsing of each other by two *bright* stars of somewhat different size revolving close together. This, however, does not explain all of the details of the variations, and stars of the Beta Lyræ type are still among the unsolved problems of the skies.

The other types of short-period variables are severally classified, but these subdivisions need not be discussed here. It is probable that the changes of all are due to a great extent to the close revolution and eclipses of two or more stars, in some cases whirling in actual contact with each other, and also to a real flaming out of the stars themselves.

Our Sun has recently been proved to be a variable of short period, but the variation is so extremely slight as to be measurable by only the most delicate instruments. This, and the fact that almost all variables (where the constitution of the star itself causes the change) are of a reddish tinge, some long-period variables, indeed, being veritable rubies in color, lends plausibility to the theory that variability is a sign of advancing stellar age, and that it is caused in many cases, by extreme conditions similar to those producing the solar spots and prominences.

Another theory attempting to explain variability in stars is based upon a partial or grazing collision of two stars. In such occurrences it is argued that a great rift or valley would be gouged out of each star, leaving that part of each a mass of flaming gases raised to an enormous heat by the impact and friction of the collision. A secondary effect of such a collision would be the rotation imparted to each star so that it would sweep through the skies a brilliant beam of light emanating from its torn side as does a lighthouse with its revolving search-light.

Of Long-Period Variables many are known. Some of these pass through their changes with a real regularity, while others are so erratic that no period or cycle can be stated. In fact, these irregular variables seem to scorn any degree of constancy, and the maximum of one rise may fall far short of previous brilliancy. The extreme rapidity with which some of these freaks "rise" is astounding. In some cases only three or four days is necessary for one to rise to a maximum forty times more bright than its minimum.

The most noted long-period variable is Mira "the Wonderful" of the constellation Cetus. This has been under observation for over three hundred years, and is the first of these stars to be recognized. In the course of about 331 days Mira changes slowly and evenly from a star of over second to one of less than ninth magnitude, and back again; so that, while at maximum it is one of the most conspicuous stars, it is for over five months of its cycle invisible to the naked eye. It gives at maximum about *375 times* as much light as at minimum.

By careful study of these long-period variables it has been possible to classify many of them according to their "light-curves," and continued observation and spectroscopic study will without doubt discover the causes for all the various peculiarities of these "freaks."

New Stars. Occasionally the careful observer of the skies will note a star where previously none was to be seen, and which is not charted. This is called a new star, or technically a Nova.

The causes, or cause, of these sudden appearances, for sudden they indeed are, is not definitely known, but it is certain that they are evidences of some enormous cataclysm. It is generally accepted that a Nova is the result of a collision of some sort between two stars. The main result of such a collision, whether a partial or grazing one, or a head-on meeting, between any bodies traveling at the speed common in the universe, would be the transformation into an incandescent mass of gas of all the directly colliding matter, which, radiating with a surpassing brilliance, would shine to us as a star.

Whether these collisions took place between dark stars or bright stars, or a bright star and a dark star, the result would be the same, varying only in intensity according to the size and density of the colliding bodies.

There are many subdivisions of the star-collision theory, and certain objections to it are advanced, all of which are of too technical a nature to be given here. The dissenters offer other theories, such as the passage through a dark nebula by a star, either bright or dark, and the consequent heat and incandescence from friction; the collision of meteor swarms; or the *actual explosion of a star by atomic disintegration*. This last suggestion, which science is finding not so improbable as it sounds, is not the most pleasant to contemplate, for granting the truth of it admits the possibility of our Sun not denying itself as long as we Earth dwellers should prefer an explosive debauch of this kind, which would wreck the whole Solar System.

New stars seem to pass through about the same general changes. They flash up from nothing to widely ranging degrees of brilliancy, some never being visible to the naked eye, and others being, for a time, the most conspicuous of the stellar host. Their maximum brightness is held for a comparatively short period, and they then fade slowly, occasionally blazing up briefly as if in vain attempts to retain their passing glory. The decrease, however, is always great, and a Nova, as a rule, either entirely disappears, or remains as a very faint, and often nebulous, star, usually a variable.

Novæ that rise to great magnitude are rare. This is unfortunate, as it is difficult to make proper spectroscopic study of faint stars, and we must look to the spectroscope to obtain the facts required to explain these curiosities of the skies. Theoretical discussion has, as we have said, produced many theories, but a few more opportunities to observe brilliant Novæ will very possibly remove them from among the unsolved problems, to the realm of fact.

The first Nova mentioned was that observed by Hipparchus in 123 B.C.—and its sudden appearance so upset his notions of the permanency of the stars that he began the first great star catalog.

The most famous and the most brilliant on record appeared in 1572, in the constellation Cassiopeia. This was studied by Tycho Brahe and is often referred to as Tycho's star. It was at one time so bright as to be visible in daylight. There is now absolutely no trace of it.

Of recent years, the brilliant Novæ have been Nova Auriga and Nova Persei. Both of these were discovered by a Dr. Anderson of Edinburgh, a naked-eye observer, in 1892 and 1901 respectively. The latter was extremely brilliant, and rose in twenty-four hours from total invisibility (the region was photographed the day before it was seen and showed no trace of such a star) to third magnitude, and speedily attained first magnitude.

It was from this star that a nebula seemed to spread with amazing velocity. It is yet unknown whether this nebula was actually formed and radiated as it appeared, or whether it was an existing dark nebula into which the star rushed, thus becoming brilliant, the nebula itself growing visible only as the light from the flaming star rushed outward. The next brilliant Nova may throw our way light enough to reveal the answer.

There have been many other new stars observed but only about nineteen of them since the time of Hipparchus have been of noticeable brilliancy. Nowadays, they are usually found by photography, a comparison of two plates of the same region showing immediately any discrepancy between them, and such discrepancies being immediately investigated. A general spectrographic photograph of a region of the skies will often show Novæ, as they have peculiar spectra easily recognized by experts. There is nothing which so stirs the astronomical world as the discovery of a brilliant Nova.

CHAPTER XIX

ASTRONOMICAL INSTRUMENTS

THE more important instruments used in the modern observatories are: the Telescope; the Spectroscope; the Photographic Telescope; the Meridian Circle; and the Astronomical Clock. There are many other special instruments as, for instance, one which shows the amount of light reaching us from an object; another which estimates the amount of heat received; and a number of attachments for the telescope which assist in making delicate measurements of the size and distance apart of objects viewed. The description of these special instruments would be out of place here.

THE TELESCOPE

In complete form, as used in observatories, the telescope and its mounting is a complicated structure. The principles of the instrument can, however, be readily understood.

The main function of a telescope is to make distant objects look near. The optical appliances by which this is accomplished are very simple. They are merely lenses of glass, ground with great perfection. The most necessary part of the instrument is a means of collecting light coming from an object, so that an image of the latter may be formed. This light-collecting is done either by passing the light *through* a lens, or by reflecting it from a concave mirror of glass or metal. It may be seen, therefore, that there are two main classes of telescope: the first being called the Refracting Telescope, or Refractor; the second, the Reflecting Telescope, or Reflector.

The REFRACTING TELESCOPE. The lenses of a refractor are the object-glass, or *objective*, and the eyepiece. The former collects the light and forms an image of the object at its *focus*, at the other end of the telescope tube, and the latter magnifies this image as desired. Telescopes have but one objective, but, as a rule, are fitted with eyepieces of widely ranging magnifying power, for different uses.

The objective is nearly always of two pieces so closely put together as to seem one. This is to avoid what is known as the *dispersion* of a lens. The reader probably is aware that ordinary light is composed of a great number of colors, which can be separated by passing the light through a prism, this resulting in the "rainbow" effect known as a *spectrum*. In fact a rainbow is simply the Sun's light dispersed by the countless rain-drops acting as lenses. It is most essential that an object-glass bring to a clear focus *all* the rays coming from one point of the object being viewed. A single lens will not do this since it invariably has dispersive power and, in consequence, the red rays, at the lower end of the spectrum, are brought to one focus, while the violet, at the high end, are concentrated at another, the in-between colors each having a focus of its own. As a result, the image is not only blurred and indistinct, but shows an unnatural colored appearance. Troublesome as this is to astronomers in connection with their telescopes, it is nevertheless a great blessing, for it is upon the dispersive power of glass that the wonderful spectroscope depends.

In 1750, Dollond of London found that, by using two kinds of glass of widely different

THE GREAT SOUTHERN STAR-CLUSTER ω CENTAURI

One of the best two examples of a true star-cluster
Note the streaming of small stars around the cluster. The stars of the cluster itself are too numerous to be counted, or even to be separately distinguished in the central part
Photographed by S. I. Bailey at the South American Station of Harvard Observatory

dispersive powers, it was possible nearly to correct this fault. However, even in the best lenses it is present to a small degree, and a bright image always appears surrounded by a bluish radiance, arising from those violet rays not properly brought to a focus.

The objective is by far the most important part of the telescope, and the power of the instrument is limited by the diameter of this lens, the *aperture*, as it is called. In order to see an object one must have a certain amount of light, and to magnify an object and still see it at its original brightness requires more light. If we magnify one hundred times, we need ten thousand times the light to keep the object at its natural illumination. It is possible to see and study most celestial objects when seen far below their normal illumination. A power of 200 can be used upon only a 3-inch telescope with comfort and advantage when studying the Moon, for instance, although a 3-inch glass collects only 225 times more light than the eye. It does not follow, however, that because a lens twenty inches in diameter collects about 10,000 times as much light as does the naked eye, it will be possible to use a magnification of 10,000. The reason for this is explained later.

An objective may be of tremendous light-gathering power and yet be worthless, for, unless it bring properly to a focus the rays striking it, the image formed is too blurred to be seen with any advantage. The focusing quality of a lens is called its *definition*. The slightest deviation from the proper shape of a lens affects its definition. The larger the objective the more serious any such errors become, as more light is incorrectly focused.

The making of a good objective, therefore, is a most difficult task. The manufacture of the glass disks from which it is to be ground requires great skill and patience, since the slightest flaw in the disk or the smallest inequality of density in the glass renders it useless for the purpose. Moreover, the grinding of a lens demands almost genius. "A generation ago there was but one man in the world in whose ability to make a perfect object-glass of the largest size astronomers everywhere would have felt confidence."

The image formed by the objective is always *inverted*. This makes no difference from an astronomical viewpoint, and the astronomical eyepiece makes no change in the position of the image. A terrestrial eyepiece, however, such as is used in spy-glasses, has two additional lenses which re-erect the image, and it is seen right side up.

The eyepieces of a telescope are nothing more than small magnifying glasses somewhat like those used by a watchmaker. The shorter the eyepiece, or its *focal length*, the greater the power. They are usually made of two or more lenses arranged in various combinations.

The Reflecting Telescope was invented by Newton about 1670 in consequence of his discovery of the "decomposition of light," or dispersion, which caused such trouble with refractors. It differs from the refractor mainly in that its light-collecting part is a curved mirror of glass or polished metal. This form of instrument has many advantages over the refractor. It is free from the trouble caused in the latter by the dispersion, for all light is equally reflected. It can also be made larger than the other, as it does not require great disks of glass perfect *throughout*, and does not cost as much to make. On the other hand, there are several disadvantages to the reflector type. It is impossible to get as good definition as with a refractor, since an error in a lens affects the image only one third as much as a similar error in a mirror. There is also constant trouble in keeping the polish on the mirror surface, a lack of polish meaning, of course, a corresponding loss of light. There is also more difficulty in handling this instrument; and finally, the reflector gives a fainter image, as light is lost by the double reflection described below.

The large mirror of a reflector is called technically the *speculum*. For many years this was made of an alloy called speculum metal. Now, however, glass is used, and the reflecting surface covered with a thin coating of polished silver.

It will be readily seen that there are practical difficulties in using a reflector. The most obvious one is that the rays are reflected back in the direction from which they came, and to see the image the observer must look into the mirror, so to speak. If he does this directly, his head will cut off from the mirror a large portion of the light. Some means of obviating this difficulty, therefore, is necessary, and from this necessity have come the four forms of reflectors.

The Herschelian form is practical only with large instruments, since the head of the observer is still somewhat in the way. The speculum in this form is not set squarely, but is tilted so that the image is formed close to one side of the open end of the tube. This method is no longer used.

The Cassegrainian has a small mirror near the focus of the speculum which reflects the ray back through a hole in the speculum, at which hole the eyepiece is mounted. There are but one or two of this kind in use.

The Gregorian is like the above save for a difference in the small mirror.

The Newtonian form is by far the most common, and is the most convenient to use. Here the rays are reflected, usually by a prism, through a hole in the *side* of the tube.

The POWER of a telescope depends upon the combination of objective and eyepiece.

Theoretically by using an eyepiece of sufficient power we can get any magnification we please, but there are many difficulties in carrying the magnification of an instrument beyond certain limits. First, as was said, there is the amount of light necessary to see an object under great magnification. Second, the bad definition, due to the impossibility of bringing to a focus all the light rays, grows more evident as higher powers are used. Third, and most annoying of the three, is atmospheric disturbance.

We see a celestial body through as much atmosphere as we do an object on the Earth about six miles away. In looking at such an object we see its outline blurred and softened. This is mainly because the atmosphere through which the light rays come is constantly in motion, thus causing an irregular refraction. Any one who has looked across a field on a hot day must have noticed the tremulous effect of distant objects seen through the rising heated air. This is simply an extreme condition of the always present atmospheric disturbances. The softened and blurred effect of an object thus viewed is magnified in a telescope as many times as the object itself, so that each increase of magnifying power increases the lack of definition. It is to avoid as much of this as possible, by getting above the dense sea-level air, that observatories are placed at high elevations.

Small telescopes are limited, in the high powers they may use *effectively*, to about fifty diameters to each inch of aperture. That is, a telescope with an objective three inches in diameter would find little advantage in using an eyepiece magnifying much over one hundred and fifty times. Very good object-glasses will stand, under good conditions, powers of up to one hundred diameters per inch of aperture—that is, up to certain limits. The great Yerkes refractor, for instance, with an aperture of forty inches, should, under this figuring, be able to use a power of 4000. A well-known astronomer says, however: "I doubt whether any astronomer, with any telescope now in existence, could gain a great advantage, in the study of such an object as the Moon or a planet, by carrying his magnification above a thousand, unless on very rare occasions in an atmosphere of unusual stillness."

Some of the telescopes of great size are:

Refractors

Yerkes	40	inches
Lick	36	"
Potsdam	31.5	"
Pulkowa, Nice, Paris	29.5-30	"
Greenwich	28	"
Vienna	27	"
Washington	26.25	"
Univ. of Virginia	26.25	"
Lowell Obs.	24	"

Refractors

Lord Rosse's	Diam.	6	feet
Mt. Wilson Obs.	"	5	"
Melbourne	"	4	"
Crossley Reflector (Lick Obs.)	"	3	"

THE MOUNTING OF A TELESCOPE

There is more to using a telescope than just pointing the instrument at the object, and then observing the latter. In the first place, suppose a star to be located and found in the *field*, as is termed the small patch of sky seen through the telescope. Before a proper observation can be made, the star has apparently moved out of the field, and must be followed by turning the instrument. This apparent motion is multiplied as many times as the instrument magnifies, and is in consequence quickly noticeable.

The field of view is magnified in the same way so that it covers less sky area as the power is increased. If a magnification of a thousand be used, "it would be as if we were looking at a star through a hole one eighth of an inch in diameter in the roof of a house eighteen feet high. If we imagine ourselves looking through such a hole and trying to see such a star, we shall readily realize how difficult will be the problem of finding it and of following its motion" (Newcomb).

It is to overcome these difficulties that the mounting of a telescope is devised; by "mounting" we mean the whole system by which a telescope is pointed at a star and made to follow it.

In principle the mounting is as follows:

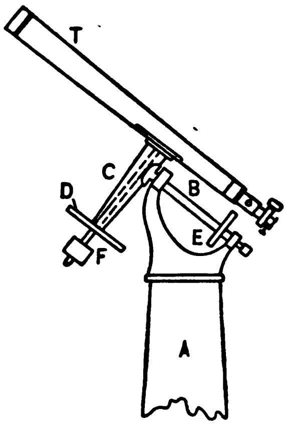
There are two axes set at right angles to each other. The main axis, the *polar axis*, is placed directly parallel to the axis of the Earth, and points therefore to the celestial poles. The other axis, the *declination axis*, turns in a "sleeve," which is fastened rigidly at right angles to the polar axis, like the cross of a T. On this second axis is mounted the telescope. When the telescope is "set" on a star, the polar axis is driven by clockwork, so that it revolves in an opposite direction to the Earth's rotation and at just the same rate. The declination axis and the telescope are turned with it, and therefore the effect of the Earth's rotation is neutralized and the star remains in the field.

The declination axis allows the telescope to turn upon it in a north and south direction only, but as the polar axis revolves in an east and west direction, the combination enables the observer to point the instrument in any desired direction.

This form of mounting is called the *equatorial*.

The accompanying diagram will help to make it clear.

There are two methods by which stars are "found," as it is called, or brought into the field. Every telescope has what is called a *finder;* this is a smaller telescope mounted rigidly on the larger, exactly parallel to it. This finder is of low magnifying power and has in consequence a large field. By sighting along the telescope it can be pointed in the direction desired, so closely that the object will be in the field of the finder. The telescope is then moved until the object is in the center of the field of the finder, and it will be then in the field of the main telescope.



A. *Pillar*
B. *Polar Axis*
C. *Sleeve of Declination Axis*
D. *Declination Circle*
E. *Hour Circle*
F. *Counter-weight*
T. *Telescope Tube*

However, as most objects an observer studies are too faint to be visible with the naked eye, and even with the finder, other assistance is needed. The position of a star is marked on the celestial sphere in *right ascension*, and *declination* corresponding to longitude and latitude on the Earth, and on the axes of the telescope are mounted graduated circles (see diagram on page 170). The *declination circle* has marked upon it degrees and fractions of a degree, so as to show the declination of the spot on the sky at which the telescope is pointed. The *hour-circle* is divided into twenty-four hours, and each of these again into sixty minutes, since right ascension is, for convenience, measured in *time*, not degrees. To find a star, the telescope is set at the proper declination, and after consulting the sidereal, or "star-time," clock a simple calculation shows the proper "time" on the hour-circle. The telescope is set accordingly, the clockwork started, and the object will remain in the field. This may seem complicated, but it is a very simple process.

The circles of a telescope must, of course, be very accurately set and marked. The best ones are of silver, and the markings are so fine that a magnifying glass is necessary to read the lines and figures upon them.

The diagram shows only the refractor type; there is no difference in the principle of the equatorial mounting of a reflector.

Needless to say, no equatorial mounting can be quite satisfactory unless permanently set on a firm pillar. Small portable instruments are sometimes equatorially mounted. In such cases it is, of course, necessary to point the polar axis as carefully as possible at the celestial poles before the telescope is in proper position to use.

The large telescopes are most complex structures. As a rule, they have more than one finder, the sizes varying, and because of their great weight the problem of handling them is great. However, this problem has been so satisfactorily solved that the observer at a well-equipped telescope "presses the button," and the rest is done for him by motors and clockwork.

THE SPECTROSCOPE

The spectroscope is an instrument for analyzing light. This sounds more as if it belonged in the laboratory of a physicist than in the observatory of an astronomer. It is, however, by its marvelous aid that more has been discovered about the universe and its individual parts than it seemed possible for man to learn. Without doubt, its wizard-like reading of the secrets of the cosmos place it as the foremost wonder of the world. The value of the spectroscope is just barely being recognized. Not until about 1860 was its analytical eye turned upon the heavens with a proper understanding of the great knowledge which it could reveal, although the first principle of spectroscopic analysis, "decomposition of light," was discovered by Newton.

This first principle is commonly known, and is, as mentioned in the paragraphs upon lenses, that white light is composite, consisting of various colored lights which are spread out, or dispersed, when passed through a prism of glass or some refracting material.

The sensation of light is produced when the retina of the eye is struck by waves or vibrations in the ether, which pervades all matter, providing these waves move with the proper speeds. The slow light waves produce the sensation of red light, the most rapid that of violet, and between these two the various "rainbow" color sensations are the result of various speeds of waves. White light is composed of all these various wave lengths mixed one with the other, somewhat similar to the way great ocean waves are, on a windy day, covered by a multitude of smaller or shorter ones.

When a beam of light is passed through a prism, it is separated into these colors, each class of wave length being refracted, or bent to a different degree, but all of each class invariably undergoing the same amount of refraction, and a "rainbow" effect results, with the red at one end and the violet at the other. When the original light is passed through a narrow slit, an even band of colors is obtained; this is called a *spectrum*.

These colors are not sharp and distinct, but shade by perfect gradation each into the next, so that it is barely possible to say where one begins and the other ends.

The spectroscope is designed to allow the light to pass first through a slit and then through a prism, or series of prisms where a wider dispersion is desired. A closely ruled, reflective glass "grating," giving the same effect, is now largely used instead of a prism. The spectrum is then observed through a small "view-telescope," or photographed.

Briefly, the principles of spectroscopic analysis are:

Different forms of matter give different spectra. Every spectrum is crossed by certain lines, each line, or series of lines, being produced by one "element" and by *no other;* and these lines always appear in the same relative positions. A skilled spectroscopist is able to say immediately upon seeing a clear spectrum that it was made by light coming from specific materials, for a knowledge of what substances produce certain lines has been built up by actual tests in the laboratories. In connection with this, it is interesting to note that helium was discovered in the Sun many years before it was found on the Earth. Its lines were present in the solar spectrum, but not until helium had been chemically reduced was it possible to produce artificially a spectrum showing those lines.

Light, as has been shown, laughs at distance, and traverses billions of miles unchanged. It makes no difference, therefore, whether it is a star many light-years away or a lamp a few feet off which is examined by the spectroscope. As long as there is enough light to give a spectrum, analysis is equally possible.

The spectroscope is also used to measure star velocities in our line of sight—that is, coming toward or receding from us. If a star is approaching us, the spectroscope "runs into" more than a normal number of light waves per second, and all the spectrum lines of that star are shifted toward the violet or rapid end of the spectrum; and, if the star be receding from us, the shift is toward the red or slow end, since then less than normal the number of waves reach the instrument. By this shift, the speed of the star's motion can be closely estimated.

By this principle are observed the binary stars which are too close together to be separated visually. If two stars revolve in regular orbits about each other, each will first approach and then recede from us, in the period of one revolution, and the spectrum will show a *double* system of lines, first separating, then closing together till they merge, and then separating again in the opposite direction.

Nowadays the spectroscope is, as a rule, used not visually but photographically, and the spectra are studied and measured at leisure. As in other branches of observational astronomy, the use of the camera has been of inestimable value in spectroscopy.

For obtaining spectra of stars, nebulæ, and faint objects in general, the spectroscope is attached to the eyepiece end of a telescope that it may take advantage of the light-collecting power of the large instrument.

The writer wishes that more space could be devoted here to this marvelous instrument and its use, for we already owe to it much of our most interesting knowledge of astronomy, and it is unquestionably by an extension of spectroscopic work that the answers will be found to many as yet unsolved problems.

THE PHOTOGRAPHIC TELESCOPE

As has been stated in the previous pages, astronomers are turning more and more to the photographic plate as a means of not only recording observations for further study, but also of making observations beyond the limits of eyesight.

The photographic plate is peculiarly sensitive to rays of light which are too rapid for the eye to grasp, and so, though an ordinary telescope will serve the purpose fairly well, the instrument for photographic use is given an objective especially designed to focus these rapid rays. As an ordinary camera, mounted equatorially so as to follow the stars, will, with a few minutes' exposure, record more stars than can be seen by the naked eye, it may readily be imagined what a long exposure with a photographic telescope will do. No eye can see the wonderful nebulosity in the Pleiades, as shown in the frontispiece, nor one half the extent of the great Orion nebula; and while a star of about the 17th magnitude is at the *visual* limit of our telescopes, the camera plate "sees" down to the 20th magnitude. Particularly in the study of comets and nebulæ, has the sensitive plate proved of very great and growing value; while in recording solar disturbances and in charting the stars it is almost indispensable. Only in planetary work does it fail to equal direct vision, and here the fine surface detail desired is blurred and lost because of the atmospheric disturbances during the exposure.

There are moments when the atmosphere is almost absolutely steady and clear. When observing visually, such a moment need be but a fractional part of a second for the eye to catch a sufficient glimpse of even the finest detail. The photographic plate, however, needs at least a couple of seconds to receive and record an impression of faint detail. It is for this reason that in planetary work the eye is still superior to photography. Further improvements in the sensitizing of plates will unquestionably overcome the present difficulties.

Except for the specially figured objective, and the fact that it is of shorter focus so that a greater field may be taken in, the photographic telescope differs in no basic way from the ordinary refractor. A refractor is equally good for photographic and visual work, as all rays are equally reflected, though unequally refracted.

THE MERIDIAN CIRCLE

This is a telescope used in determining the exact position of the celestial bodies. It is especially mounted so that its only motion can be north or south, *along the meridian*. If it points exactly south, it can be turned on its axis until the line of sight passes through the zenith and still farther through the pole to the north horizon; but it cannot be turned a hair's breadth east or west. In the field of this instrument is a fine "spider line," exactly marking the meridian. There is also, as a rule, a *series* of lines flanking the one actually on the meridian.

The right ascension of a star is the same as its sidereal time of crossing the meridian, so that the problem of finding the former is theoretically simple. The sidereal clock is started, set exactly at the correct sidereal time, the telescope of the meridian circle pointed at where the star will cross its field, and the exact moment when the star passes the meridian is noted. The time by the sidereal clock then shows the star's right ascension. This indeed should be simple, but unfortunately there are irregularities to be reckoned upon. It is impossible to make a clock of the exactness required by an astronomer, and there is always some slight error in the placing of the meridian instrument. There is also the error of personal equation to be considered, no two people seeing and acting in just the same time, so that where one observer will record a star's passage as too early, another will do so too late. Allowances must be made for all these possible errors, and therefore, the determination of a star's right ascension is really a difficult matter.

The declination of a star is read by microscopes from very carefully ruled circles that turn with the telescope. There is also the possibility of instrumental error here, but the personal equation is eliminated, since the reading need not be made at a precise moment, as is necessary in noting the transit of a star across the meridian.

In speaking of errors in recording the time of a transit, but tiny fractions of a second are meant. Most observatories use a *chronograph* to record this time. The chronograph consists of a revolving cylinder, covered with paper upon which rests a pen point, so that, as the cylinder revolves, the pen traces a line upon the paper. The paper is so connected by an electric current passing through the clock, and through a key held by the observer, that every beat of the clock and every pressure on the key make a notch or dot in the pen line. When the observer sees a star on the spider line in his instrument he presses the key, and the position of the notch thus made in the pen trace, between two notches made by the clock, gives the exact moment at which the key was pressed.

It is from these observations that the astronomers figure and give out the correct standard time by which the clocks and watches of the whole world are set.

So difficult is it to secure and obtain the necessary accuracy of all parts of a meridian circle and its accessories, that the "meridian chamber" of an observatory is the "holy of holies" to the staff, and only the most favored visitors gain admittance there.

THE ASTRONOMICAL OR SIDEREAL CLOCK

This is merely a most accurate timepiece, of pendulum action, regulated to run "star-time," the day of which is about three minutes and fifty-six seconds shorter than the standard civil day. The sidereal day is the *exact* time the Earth requires to complete one full revolution; while the standard day is the average time between successive solar noons, or returns of the Sun to the meridian; this, because of the Earth's revolution about the Sun, requiring somewhat more than one complete rotation of our globe.

A sidereal clock gains on our ordinary clock about two hours a month, or twenty-four hours in a year. Therefore, in a year of 365 days, the Earth has completed 366 rotations, and, in a leap year, 367.

CHAPTER XX

CHRONOLOGY

The science of Astronomy is without doubt the oldest of the true sciences. Its early history, like that of all histories, is lost in the depths of time, but the records of the ancients carry it dimly to about five thousand years ago. These records, moreover, are such that they demonstrate a close study for centuries previous.

Unquestionably the rising and setting of the Sun and the Moon, and the phases of the latter, the most evident of celestial phenomena, must have caused a wonderment and thought at the very dawn of human intelligence. From that first wonderment to the first astronomical records is a time measured only by conjecture.

The earliest records known are those of the Chinese. Then come those of the Babylonians and the Egyptians. It is interesting to note that from some of the Babylonial observations, inscribed upon baked bricks lately excavated, it has been possible to obtain values of some of the Moon's motions accurate enough to be of real assistance in a recent revision of certain lunar tables.

Not till the time of the later Greek philosophers, however, do we get connected data. It was among the last mentioned that real observational astronomy began. That the Greek nature philosophers devoted much thought to the structure of the Universe is shown by the fact that we can pick from their theories enough of what we now know to be true to give a fairly accurate description not only of the Solar System but the Universe at large. Copernicus, who hundreds of years later evolved the true *basic* plan of the Solar System, credits not himself, as the originator of the theory, but Pythagoras (B.C. 569–470).

Unfortunately for the progress of the science, these early philosophers propounded, with their average one true theory apiece, so many absurd conceptions that the conservative thinkers chose to remain supporters of a theory confirmed, or apparently confirmed, by what they themselves saw. It is for this reason that, though great strides were made in observational work, a marvelously ingenious, complicated, and sadly false theory of the system of the Universe was accepted, and held sway for centuries, being superseded only by the present so-called Copernican Theory after the great Kepler had "smoothed out the wrinkles" in this latter.

Through the Middle Ages, the false theory, evolved by Ptolemy, was believed in so tenaciously that the world at large refused to accept the true facts when they were presented. The removal of the Earth from the center of the Universe to the insignificant position of an attendant upon a body supposedly created merely to give light and heat to the Earth was too much for humanity to admit. Indeed, much was done to stamp out this new be-littling doctrine. History sadly points to Galileo as an old man denying, under threat of torture, the cosmic system he knew to be true, and even more sadly to Bruno, previously burned at the stake for refusing to abandon such heretical beliefs.

From then on, however, the path of Astronomy has been broad and clearly lighted, Kepler and the mighty Newton being responsible, so to speak, for the larger part of the illumination. It is upon Kepler's demonstration of the true motions of the planetary bodies (and would it were possible to devote many pages here to this greatest of all astronomical achievements) and Newton's magical demonstration of the ***universal rule*** of that Gravitation, known since early times, that modern Astronomy stands.

Previous to the time of Galileo, astronomical instruments were of the most primitive and crude construction, and were, in consequence, of feeble assistance. After the invention of the telescope, and its improvement by Galileo, these instruments have evolved with marvelous speed, until now, with the amazingly accurate measuring attachments to the telescope; that greatest wonder of all the ages, the spectroscope, the analyzer of light; and the photographic plate, that magic recorder of the faintest impression of light, it seems that we have reached the limit of the science of optics. However, that some new and still more marvelous improvement or invention will appear seems, from analogy, to be almost certain. Many times before has Man been at the apparent limit of his abilities, only to step boldly and successfully beyond.

Directly following is a chronology of the main events of Astronomy. For the first part it is necessarily general and broad; but from the time of Copernicus to the present, it is accurate according to the accepted historical dates.

CHRONOLOGICAL TABLE

Previous to the 5th Century B.C.

A few ancient records have come down to us, which demonstrate the fact that even in those remote years astronomy was by no means a new science.

There are reports of celestial spheres made in China in the 29th century B.C. and another in the 23d century B.C.

It is said that in 2513 B.C. the Emperor Chueni of China recorded a conjunction of five planets, and that Yao gave instructions to his astronomers to determine the positions of the Equinoxes and the Solstices; also that, at this time, the calendar year was of 365 days with an added day every four years, as in our present calendar.

In 2159 (?) B.C. two Chinese Royal Astronomers were put to death for neglecting to predict an eclipse.

Records have been found of comets and eclipses running back to 1640 B.C.

The Saros or eclipse cycle used by the Egyptian and Chaldeans.

Thales (639–546 B.C.), the Greek nature philosopher, explains the phases of the Moon, and measures the angular diameter of the Sun.

Parmenides shortly afterward declares the Earth to be a sphere.

Pythagoras (569–470 B.C.) deduces the theory of planetary motions, which Copernicus later revised. **5th Century B.C.**

Meton (432 B.C.) introduces calendar reform. The Metonic cycle is still used to determine the date of Easter.

Democritus (470–? B.C.) evolves true conception of the Universe.

Heraclitus supposes Earth to rotate upon axis.

Callipus (330 B.C.) corrects eclipse cycle. **4th Century B.C.**

Aristarchus (320–250 B.C.) measures distance of the Sun.

Eratosthenes (276–196 B.C.) measures Earth and inclination of the axis to the ecliptic. **2d Century B.C.**

Aristillus and Timocharis fix positions of zodiacal stars.

Hipparchus (190–120 B.C.) founds real observational astronomy; again measures inclination of axis; remeasures length of year; computes lunar tables; observes first recorded "new star"; makes first great star chart; discovers precession of equinoxes; invents trigonometry.

Ptolemy (139–161) formulates his theory of celestial motions. **2d Century A.D.**

Alexandrian library burned by Caliph Omar. **7th Century**

Moon's variation noted by Abul Wefa. **10th Century**

Ulugh-Begh makes first star catalogue since that of Hipparchus. **15th Century**

Copernicus born. **1473**

Astrolabe invented by Behaim. **1480**

Copernicus publishes *De Revolutionibus Orbium Celestium*, his great work, recalling **1543** as a basis the theory of Pythagoras, thus beginning the great advance made by astronomy in the last five hundred years.

Copernicus dies.

1546 Tycho Brahe born. The most diligent and accurate observer since Hipparchus. He invented and made many instruments, necessarily crude, with which, however, he did marvelously accurate work. On his observations were founded Kepler's laws.

1564 Galileo born.

1571 Johann Kepler born. He assisted Tycho for several years, and inherited his post at the death of the latter.

1572 Tycho observes a "new star," the first recorded since the time of Hipparchus. This stimulates him to make a star catalogue of great accuracy. In making this he uses corrections of his own for atmospheric refraction.

1583 Galileo discovers isochronism of pendulum.

1600 Bruno burned at the stake.

1601 Tycho dies.

1605 Brilliant "new star" observed by Kepler.

1608 (?) First telescopes made in Holland.

1609 Galileo improves telescope.

Kepler publishes his work *Astronomia Nova*, including the first two of his great laws of planetary motion.

1610 Four larger satellites of Jupiter, sun-spots, surface irregularities of the Moon, phases of Venus, discovered by Galileo with his telescope. Saturn's rings also first seen by Galileo, but believed to be illusionary.

1614 John Napier publishes his invention of logarithms.

Kepler evolves his Third Law.	1816
Kepler dies.	1630
Transit of Venus foretold by Horrocks.	1639
Galileo dies.	1642
Sir Isaac Newton born.	
First serious selenographic work done by Langrenus.	1645
John Flamsteed born. First Astronomer Royal. Maker of the first trustworthy catalogue of stars.	1646
Huyghens discovers Titan, satellite vi. of Saturn; the largest and first to be seen.	1655
Huyghens describes in cipher the rings of Saturn.	1656
Edmund Halley, Second Astronomer, Royal born.	
First pendulum clock made by Huyghens.	1657
Huyghens translates cipher on Saturn rings.	1659
Newton experiments with prism and dispersion of light.	1660 (?)
Reflecting telescope first proposed by Gregory.	1663
Cassini notes great spot on Jupiter.	1665
Cassini establishes rotation periods of Jupiter.	
Newton makes first reflecting telescope.	1666
National Observatory at Paris founded.	1667
Telescope first used as pointer by Picard.	
Cassini discovers Japetus, satellite viii. of Saturn.	1671
Cassini discovers Rhea satellite v. of Saturn.	1672
Cassini discovers division in Saturn's ring.	1675
Time required by light to travel discovered and measured by Roemer.	
Royal Observatory at Greenwich founded.	1676

1681	First transit instrument built by Roemer.
1684	Cassini discovers Tethys and Dione satellites, iii. and iv. of Saturn.
1687	Newton publishes his *Principia*, containing his exposition of the universal rule of the law of gravitation.
1691	Oval form of Jupiter observed by Cassini.
1692	Cassini makes chart of Moon.
1705	Halley first predicts return of a comet, the one now bearing his name.
1706	Solar prominences first noted.
1707–1713	Miraldi notes variation in brilliancy of Jupiter's fourth satellite.
1718	Halley detects motions of Arcturus and Sirius.
1721	Halley appointed the second Astronomer Royal.
1727	Newton dies.
1729	Bradley publishes his discovery of the aberration of light.
1738	Herschel born.
1742	Halley dies.
1743	Heliometer invented by Savary.
1748	Bradley discovers that the inclination of the Earth's axis is not constant (*nutation*).
1757	Achromatic lens invented by Dollond.
1758	Halley's Comet upon first predicted return, first observed by Palitsch.
1767	Maskelyne, Astronomer Royal, lays foundation of Nautical Almanac.
1772	Bode's "Law" discovered.
1775–94	Herschel establishes rotation of Saturn.
1781	Herschel discovers Uranus.
1782	Herschel appointed Astronomer to George III.

Goodricke advances correct theory, explaining variability of Algol.	1783
Laplace publishes elements of Uranus.	
Herschel deduces motion of Sun through space.	
Herschel discovers two satellites of Uranus.	1787
Herschel's great reflector finished.	1789
Herschel discovers the Mimas and Enceladus satellites i. and ii. of Saturn.	
Large disks of flint-glass successfully made by Guinand.	1790 (?)
Laplace publishes *Système des Mondes*. containing his theories on the Nebular Hypothesis.	1766
Piazzi discovers first planetoid (Ceres).	1801
De Zach rediscovers the lost first planetoid.	
Olbers discovers second planetoid (Pallas),	1802
Herschel discovers revolution of binary stars.	1803–04
Harding discovers third planetoid (Juno).	1804
Olbers discovers fourth planetoid (Vesta).	1807
Frauenhöfer first measures lines in solar spectrum.	1817
Herschel dies.	1822
Stower measures diameter of Jupiter's largest four satellites.	
Vast meteoric shower in America.	1833
Hopkins Observatory, Williams College, founded; oldest in America.	1836
Chart of Moon made by Beer and Maedler.	1837
Bessel first successfully measures stellar parallax.	1837–1840
Sun-spot periodicity discovered by Schwabe	1838
Pulkowa Observatory completed.	1839
Harvard College Observatory founded.	

1840	Canals on Mars first indicated in drawings by Beer and Maedler.
1842	Dŏppler evolves method of measuring velocity in line of sight of luminous body.
1843	Schwabe announces Sun-spot periodicity.
1844	Bessel pronounces Sirius and Procyon binary systems with dark or very faint companions.
1845	First photograph of Sun taken; a daguerreotype by Foucault and Figeau.
	Fifth planetoid discovered.
	Lord Rosse's great 6 ft. reflector built.
	Adams completes calculations of Neptune's position.
1846	Le Verrier completes computation of position of Neptune.
1846	Neptune found by Galle.
	Satellite of Neptune discovered by Lassel.
	Biela's comet observed to split.
1848	Hyperion satellite vii. of Saturn discovered simultaneously by Bond and Lassell.
1850	Bond successfully photographs Moon.
1851–1860	Solar prominences proved appendages of the Sun not Moon.
1851	Lamont connects variation of compass with sun-spot period.
	Lassell discovers two more satellites of Uranus.
1852	"Magnetic Storms" found to be periodic.
1853	De la Rue first uses collodion process in astronomical photography.
	De la Rue first uses stereoscope.
1857	De la Rue constructs first photoheliograph.
1859	Reversal of spectrum lines experimentally explained by Kirchoff.
1862	Clark discovers companion to Sirius.

Velocity of light found experimentally by Fizeau and Foucault independently.

Rotation of Mars deduced by Kaiser.

Carrington establishes the unequal rotation of the solar surface. 1863

Nebulæ first studied by spectroscope. 1864

Donati first observes spectrum of comet.

Spectrum of Nebula first observed by Huggins.

Spectrum of Sun-spot compared with that of solar surface by Lockyer. 1866

Return of Leonid meteorites.

Le Verrier computes elements of Leonids. 1867

Helium found in the Sun. 1868

Huggins measures velocities of stars in line of sight.

Spectroscope first used in eclipse of Sun. Solar prominences viewed by Jansen for first time without eclipse.

Dawes makes first good map of Mars. 1869

Gelatine dry plates first used in astronomical photography, by Huggins. 1876

Schiaparelli first maps Martian "Canals." 1877

Satellites of Mars discovered by Hall.

Gill more correctly ascertains distance of Sun by improved heliometer. 1877–89

Jupiter's "Great Red Spot" first observed. 1878

Sir W. M. H. Christie, Eighth Astronomer Royal takes up duties. 1881

Gill makes first comet photograph, and originates stellar chart-photography. 1882

Great star map started. 1887

Lick Observatory completed. 1888

Vogel observes orbital motion of Algol by means of spectroscope. 1889

Spectroscope reveals close binary stars (Pickering).

1890 Schiaparelli discovers true rotation of Venus and Mercury.

1892 Dr. Anderson discovers "Nova Aurigæ."

Barnard discovers Jupiter's fifth satellite.

1894 Sun-spots proved not always depressions, by Howlett.

Lowell Observatory founded.

1895 Constitution of Saturn's rings proved by spectroscope (Keeler).

Helium discovered on the Earth.

1896 Companion to Procyon discovered by Schaeberle.

1897 Yerkes Observatory opened.

1898 Pickering discovers, by photography, Phoebe satellite ix. of Saturn.

1901 Dr. Anderson discovers "Nova Persei."

1903 Sun photography improved by Hale and Deslandres independently.

1904 Mt. Wilson Solar Observatory founded.

1905 Jupiter's sixth and seventh satellites discovered by photography at the Lick Observatory.

Pickering discovers, by photography, Themis satellite x. of Saturn.

1907 Slipher of the Lowell Observatory improves plates for spectroscope work.

Slipher successfully photographs Martian Canals.

1908 Eighth satellite of Jupiter discovered by Melotte.

Eros, the nearest planetoid, discovered by Witte.

ASTRONOMICAL SYMBOLS USED IN ALMANACS

☿ =Mercury.	● =New Moon.
	☽ =First Quarter.
♀ =Venus.	○ =Full Moon.
	☾ =Last Quarter.
⊕ =Earth.	☉ =Sun.
	☌ =Conjunction; having the same Right Ascension. This does not necessarily mean at the same point on the celestial sphere, since the Declination of the two bodies may be different.
♂ =Mars.	
♃ =Jupiter.	
♄ =Saturn.	
♅ or ⛢ =Uranus.	☍ Opposition; differing 180° in Right Ascension
♆ =Neptune.	□ =Quadrature; differing 90° in Right Ascension

Examples:

☌ ♃ ♀ =Jupiter and Venus in conjunction.
☍ ♂ ☉ =Mars in opposition.
☌ ♃ ☉ =Jupiter in conjunction with the Sun.
☌ ☿ ☉ Inf.=Mercury in inferior conjunction; between the Earth and the Sun.
☌ ☿ ☉ Sup.= Mercury in superior conjunction; on the other side of the Sun from the Earth.
☌ ♀ ☉ =Venus and Moon in conjunction.

A BRIEF BIBLIOGRAPHY

The titles in this list are taken from only those books which the author of this little volume has been privileged to read, and of which, therefore, he has a personal knowledge and opinion. The omission of any title does not by any means indicate that he has not considered that book worthy of mention, but merely that he has not had the opportunity to become familiar with it. All really technical works have been left out, as it is the compiler's intention to suggest only books of a more or less "popular" nature.

Books for General Reading

ARRHENIUS, SVANTE. *Life of the Universe.* 2 vols. 16mo. 260 pp. each.

A very interesting presentation of man's conception of life from the earliest times to the present.

—— *Worlds in the Making.* 12mo. 230 pp. Illus.

A presentation of the author's theories in clear everyday language; a valuable work not only well worth the reading but most delightfully readable.

BALL, SIR ROBERT. *The Earth's Beginning.* 12mo. 384 pp. Illus.

A simple but comprehensive work.

—— *Star-Land.* 12mo. 402 pp. Illus.

The author's lectures to young people, rewritten. An excellent book to awaken interest in astronomy.

BALL, SIR ROBERT. *In Starry Realms.* 8vo. 350 pp. Illus.

A volume of the same nature as Newcombe's *Side-Lights on Astronomy.* Contains interesting chapters on: The Heat of the Sun; The Moon's History; A Visit to an Observatory; Notes on Nebulæ; Mars as a World; Extent of the Sidereal Heavens, etc.

—— *The Story of the Heavens.* 8vo. 568 pp. Fully Illus.

This author's largest and most comprehensive popular work. His ultra-conservative attitude toward theories not yet wholly substantiated is somewhat to be deplored.

BICKERTON, A. W. *The Birth of Worlds and Systems.* 16mo. 163 pp. Illus.

A most interesting book on cosmic evolution. It presents a special and original theory regarding stellar collisions. Technical in parts.

BLACK, F. A. *Natural Phenomena.* 8vo. 366 pp. Illus.

Contains interesting chapters on: The Wandering of the Poles; The Weather; The Zodiacal Light; The Turn of the Day, etc.

—— *Problems in Time and Space.* 8vo. 361 pp. Illus.

A companion volume to the above. Contains chapters on: Time; The Calendar; Measuring the Earth; Magnetism of the Earth; Movement of the Earth and Sun in Space, etc.

BÜRGEL, BRUNO H. *Astronomy for All.* 8vo 351 pp. Profusely Illus.

A large book containing much "gossipy" information not found in other volumes. Its illustrations are, in many instances, unusual.

CHAMBERS, GEORGE F. *Astronomy.* 16mo. 335 pp. Profusely Illus.

A thorough little volume of convenient size. Noteworthy particularly for its illustrations.

CHAMBERS, GEORGE F. *The Story of Eclipses.* 16mo. 208 pp. Illus.

A good résumé of this division of astronomical history.

CLERKE, AGNES M. *Problems in Astrophysics.* 8vo. 567 pp. Illus.

A rather technical and special work on the physical constitution of the Sun and stars. Despite its somewhat advanced style it contains much within the easy comprehension of the general reader.

—— *The System of the Stars.* 8vo. 403 pp. Illus.

Of the same general nature as the former volume, but not so special. Has interesting chapters on the unusual stars, the Variables and Novæ.

FLAMMARION, CAMILLE. *Popular Astronomy.* 8vo. 696 pp. Profusely Illus.

Most fascinating reading. The book is exhaustive, and the author has allowed his imagination full sway. For this reason it must be read somewhat sceptically. Too many statements of facts and figures require checking, as the book is not quite up-to-date.

FORBES, GEORGE. *History of Astronomy* 16mo. 200 pp. Illus.

A capital summary, presenting its subject in well-classified and readable form. The best short history of astronomy.

JACOBY, HAROLD. *Astronomy, a Popular Handbook.* 8vo. 435 pp. Well Illus.

A recent book by a conservative with a "stand-pat" attitude. It is divided conveniently into two parts, the first for the general reader, the second for the student.

KIPPAX, JOHN R. *The Call of the Stars.* 8vo. 430 pp. Profusely Illus.

"A popular introduction to a knowledge of the starry skies." The author has successfully blended the facts of astronomy with the legendary lore of the stars and constellations. A most readable and interesting work.

LOWELL, PERCIVAL. *The Evolution of Worlds.* 8vo. 262 pp. Illus.

A clear and logical presentation of a theory opposed to the "Nebula Hypothesis" by the foremost progressive in the astronomical world.

—— *Mars as the Abode of Life.* 8vo. 288 pp. Illus.

A summary of Professor Lowell's views on evolution, with especial reference to Mars. Well worth the reading.

—— *Mars.* 8vo. Illus.
Mars and Its Canals. 8 vo. Illus.

Volumes presenting Professor Lowell's descriptions of Mars and his theories concerning it; also reporting in untechnical language the result of his long study of the planet.

—— *The Solar System.* 12mo. 134 pp. Diagrams.

A small technical volume containing, however, much that is readily understood by the general reader. It offers several interesting theories.

LYNN, WILLIAM T. *Remarkable Comets.* 32mo. 75 pp. Illus.

A little book giving briefly the histories of the more famous comets.

MACPHERSON JR., HECTOR. *The Romance of Modern Astronomy.* 12mo. 330 pp. Illus.

The title is somewhat misleading. It is a good general book on astronomy. Contains a brief history of astronomical discoveries.

MORSE, EDWARD S. *Mars and Its Mystery.* 8vo. 200 pp. Illus.

A study of the planet for the general reader, by a strong supporter of Prof. Lowell.

NEWCOMBE, SIMON. *Astronomy for Everybody.* 8vo. 333 pp. Illus.

A concise exposition of astronomical facts.

NEWCOMBE, SIMON. *Side-Lights on Astronomy.* 8vo. 345 pp. Illus.

A collection of interesting magazine articles on astronomy and kindred subjects. Contains chapters on: Unsolved Problems; Extent of the Universe; Can We Make It Rain; Life in the Universe; How the Planets are Weighed, etc.

—— *The Stars, a Study of the Universe.* 8vo. 333 pp. Illus.

A thorough treatment of the subject. Somewhat technical, but not at all beyond the layman.

OLCOTT, WM. TYLER. *Star Lore of All Ages.* 8vo. 450 pp. Profusely Illus.

A splendid collection of all the myths of the world relating to the stars.

—— *Sun Lore of All Ages.* 8vo. 450 pp. Profusely Illus.

A companion volume to the above, treating only of the Sun.

POOR, CHARLES LANE. *The Solar System, a Study of Recent Observations.* 8vo. 309 pp. Illus.

A scholarly, but untechnical book by a rigidly conservative astronomer.

SERVISS, GARRETT P. *Astronomy in a Nutshell.* 12mo. 261 pp. Illus.

A brief summary. Devotes much of its space to describing the Celestial Sphere and its coördinates. Time and the calendar are well explained.

—— *Curiosities of the Sky.* 8vo. 267 pp. Illus.

Fascinating reading. Contains chapters on: The Windows of Absolute Night; The Wrecking of the Moon; The Passing of the Constellations; The Strange Adventures of Comets, etc.

SNYDER, CARL. *The World Machine.* 8vo. 490 pp.

One of the most readable and interesting presentations of the growth of astronomical knowledge. Well worth the reading.

TODD, DAVID. *Stars and Telescopes.* 12mo. 419 pp. Illus.

A good volume which needs reprinting. The later revisions are in the form of long footnotes, and consecutive reading is almost impossible.

TURNER, HERBERT H. *Astronomical Discovery.* 8vo. 225 pp. Illus.

Well told stories of the important astronomical discoveries; Uranus, Neptune, The Asteroids, etc.

WILLIAMS, HENRY S. *Miracles of Science.* 8vo. 343 pp. Illus.

Popular magazine articles. Good reading but inaccurate in several instances. Only the first 100 pages are devoted to astronomical subjects.

Books for Observers

BAIKIE, JAMES. *Through the Telescope.* 8vo. 291 pp. Illus.

A useful practical handbook on telescope work for the amateur.

Ephemeris and Nautical Almanac, The American. 8vo. Diagrams.

Published annually by the Government. Indispensable to the observer. It gives all figures regarding the positions of the celestial bodies, including the satellites of the planets. All predictable phenomena, such as eclipses, transits, occultations, etc., are fully covered.

GIBSON, FRANK M. *The Amateur Telescopists Handbook.* 12mo. 163 pp. Illus.

A practical handbook on the testing, the care and the use of the telescope. Contains an observer's catalog of celestial objects visible in small instruments.

HASLUCK, PAUL N. *Telescope Making.* 12mo. 160 pp. Diagrams.

A manual for those desiring to construct their own instrument.

MCKREADY, KELVIN. *A Beginner's Star-Book.* 4to. 148 pp. Fully Illus.

By far the best volume for the observer beginning work, whether with the naked eye, field-glass, or telescope. It contains a system of star-maps and charts arranged on an original and most convenient plan. The text is extremely well written, and is supplemented by an admirable observer's catalog of objects within the reach of the small instrument.

MARTIN, MARTHA EVANS. *The Friendly Stars.* 12mo. 260 pp. Diagrams.

A simple hand-book for the naked-eye observer.

The Way of the Planets. 12mo. 275 pp. Illus.

A companion book to the above, devoting itself to the planets alone.

OLCOTT, WM. TYLER. *A Field Book of the Stars.* 16mo. 163 pp. Charts.

The most convenient, and the best small book for the naked-eye observer. To each constellation is devoted a special chart, with a full description on the page facing it. Tables of all the well-known meteor-showers are given.

—— *In Star-Land with a Three-Inch Telescope.* 16mo. 146 pp. Charts.

A companion volume to the Field Book. Not as full as the *Beginner's Star Book*, but the best small volume for its purpose.

PROCTOR, MARY. *Half-hours with the Summer Stars.* 16mo. 230 pp. Illus.

A reprint of some charming newspaper articles which appeared a few years ago. The volume contains in its introduction a fine description of the Yerkes observatory.

PROCTOR, R. A. *Easy Star Lessons.* 8vo. 240 pp. Illus.

A standard book, well arranged.

—— *Half-Hours with the Stars.* 4to. pp. 12 maps.

An easy guide to the constellations.

Books on the Moon

FAUTH, PHILIP. *The Moon in Modern Astronomy.* 8vo. 160 pp. Illus.

A summary of twenty years' selenographic work, and a study of recent problems.

Not only excellent special reading, but most useful to the observer. Contains many *detailed* charts, drawn by the author.

MOREAUX, THE ABBÉ *A Day in the Moon.* 12mo. 199 pp. Illus.

A special volume in untechnical language.

NASMYTH AND CARPENTER *The Moon, Considered as a Planet, A World, and a Satellite.* 12mo. 315 pp. Illus.

One of the most interesting books on the Moon. It devotes much space to the exposition in simple language of the authors' theories regarding the origin of the lunar surface markings.

SERVISS, GARRETT P. *The Moon, a Popular Treatise.* 12mo. 248 pp. Illus.

A very readable book in the form of conversations. Contains a fine series of photographs.

RUDAUX, L. *How to Study the Stars.* 12mo. 360 pp. Illus.

Instructions on the use of the telescope, and much very valuable information on astronomical photography for amateurs. A full chapter is devoted to naked-eye observing.

WEBB, REV., T. W. — *Celestial Objects for Common Telescopes.* 2 vols. 12 mo. 233 and 280 pp.

Volume I is restricted to the solar system, vol. II covering the rest of the universe. By far the most complete observer's catalog of its class. It has been standard for years, and is invaluable for its purpose.

Text Books

HOLDEN, EDWARD S. — *Elementary Astronomy.* 12mo. 446 pp. Illus.

NEWCOMB, SIMON AND HOLDEN, E. S. — *Astronomy, for High-Schools and Colleges.* 8vo. 501 pp. Illus.

TODD, DAVID. — *A New Astronomy.* 12mo. 480 pp. Illus.

YOUNG, CHARLES A. — *The Elements of Astronomy.* 12mo. 438 pp. Illus.

—— — *General Astronomy.* 8vo. 600 pp. Illus.

Atlases

PECK, W. — *The Observer's Atlas of the Heavens.* Folio. 30 Maps.

Contains several catalogs of double stars, variable stars, clusters, etc. There are several special plates of much value. A capital chart of the Moon is also included. The maps and charts are supplemented by a well-written text containing many most convenient and useful tables. It is the best atlas for the user of a small instrument.

PROCTOR, R. A. *A New Star Atlas.* 7th Ed. Folio. 12 Maps and Index Maps.

For long the standard atlas, and by many still considered the best.

SCHURIG, RICHARD. *Tabulæ Cælestes (Himmel's Atlas).* Folio 8 Maps and Moon-Chart.

The best cheap star-atlas. The text is in Latin and German, but there is not enough of it to make a translation necessary.

BARRETT, LEON AND SERVISS, GARRETT P. *Star and Planet Finder.*

The only good planisphere, and the only one by which the positions of the planets, the Sun, and the Moon can be found for every day of the year. It is convenient and easy to use, and, until a general knowledge of the constellations is gained, of great assistance to the observer.

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